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by

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A Demonstration near Regina Saskatchewan, of the Application of Treated Municipal Sludge to Agricultural Land

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ABSTRACT

In 1987 and 1988, dewatered sludge from the Regina Municipal Sewage Treatment Plant was applied to three plots of farmland in the immediate vicinity of Regina Saskatchewan. Crop performance was compared to that of fertilized plots and control plots (where no nutrient supplements were applied). Nutrient and trace element content of grains, vegetation, and soil were monitored to determine whether crops experienced any adverse or unusual effects.

Analysis revealed that crops grown on sites where sludge had been applied showed yields and protein contents that were the same as crops that were grown on chemically fertilized land. The significant variation between crops from "sludged" and fertilized land was a higher concentration of zinc in the vegetation of some of the "sludged" crops. Concentrations of copper in the soils were shown to be significantly lower than background levels on the control and fertilized plots and were not found to be significantly different from background levels on the sludged plots. It was also found that the overall cost associated with the application of sludge on a large scale can be less than the cost of chemical fertilization.

It was concluded that dewatered Regina sludge could promote satisfactory crop growth on heavy clay (dark brown) type soils in the Regina area. There was no evidence of abnormal levels of trace element accumulation in the soil, and nutrient concentrations remained within acceptable limits.

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TABLE OF CONTENTS

ABSTRACT i
ACKNOWLEDGEMENT. ii
TABLE OF CONTENTS iii
LIST OF TABLES iv
LIST OF FIGURES vi
APPENDICES vii

1 INTRODUCTION 1

2 METHODS 2
2.1 Description of Study Area 2
2.2 Field Methods 5
2.2.1 Soil Sampling 5
2.2.2 Crop and Vegetation Sampling 7
2.2.3 Sludge Sampling 8
2.2.4 Sludge Application 8
2.2.5 Fertilizer Application 9
2.2.6 Herbicide Application 10
2.2.7 Seeding Methodology 10
2.2.8 Measurement of Crop Yields 11
2.3 Laboratory Methods 11
2.4 Statistical Methods 11

3 RESULTS - DISCUSSION 12
3.1 Crop Yield 13
3.2 Grains 13
3.3 Vegetation 14
3.4 Soil 15
3.5 Sludge 16
3.6 Analysis of Crop-Available Nutrients From Sludge and Chemical Fertilizer Applications 16
3.7 Economic Evaluation - Sludge vs. Fertilizer Application 18
3.8 Errors, Omissions, and Comments 21

4 CONCLUSIONS 23

REFERENCES 24

LIST OF TABLES

1	Soil Sampling	5
2	Crop and Vegetation Sampling	7
3	Sludge Application	9
4	Commercial Fertilizer Application	9
5	Herbicide Application	10
6	Crop Application	10
7	Comparison of The Characteristics of Sludged and Fertilized Plots	12
8	Calculation of Costs of Sludge And Chemical Fertilizer Application	20
9	Cost Comparison of Sludge vs. Chemical Fertilizer Application	20
10	1988 Crop Yields	26
11	1989 Crop Yields	26
12	1989 Crop Yields - t tests	27
13	1989 Grain Samples - Protein Content & Trace Element Concentration	29
14	1989 Grain Samples - t tests	30
15	June 1988 Vegetation Samples - Protein Content & Trace Element Concentrations	32
16	June 1988 Vegetation Samples - t tests	33
17	July 1988 Vegetation Samples - Protein Content & Trace Element Concentrations	34
18	July 1988 Vegetation Samples - t tests	35
19	July 1989 Vegetation Samples - Protein Content & Trace Element Concentrations	36
20	July 1989 Vegetation Samples - t tests	37

(... Continued)

LIST OF TABLES (Continued...)

21 September 1987 Soil Samples - Background Nutrient and Trace Element Concentrations 39

22 September 1988 Soil Samples - Nutrient Content 40

23 September 1988 Soil Samples - t tests 41

24 September 1989 Soil Samples - Nutrient & Trace Element Concentrations 42

25 September 1989 Soil Samples - t tests 43

26 Characteristics of Applied Sludge 45

27 Characteristics of Commercial Fertilizers 47

28 Crop Available Nitrogen Calculated Using The USEPA Method, For Specific Rates of Sludge Application 49

29 Recommended Rates of (Nitrogen) Application for Wheat Crops Grown in The Dark Brown Soil Zone of Saskatchewan 49

30 Crop Available Nitrogen Resulting From Sludge Application 50

31 Crop Available Nitrogen Resulting From Commercial Fertilizer Application . . . 51

LIST OF FIGURES

1 Study Area 3

2 Layout of Sites 1, 2 and 3 4

3 Field Methods - Sites 1, 2, and 3 5

APPENDICES

A YIELD DATA 25

B GRAIN DATA 28

C VEGETATION DATA 31

D SOIL DATA 38

E CHARACTERISTICS OF REGINA MUNICIPAL SLUDGE 44

F CHARACTERISTICS OF COMMERCIAL FERTILIZERS 46

G NUTRIENT ACCUMULATION CALCULATIONS 48

H LABORATORY METHODS 52

1 INTRODUCTION

In 1987, a study was undertaken to demonstrate that dewatered municipal sewage sludge (the sludge referred to by this paper is the solid waste by-product of the treatment process at the Regina Municipal Sewage Treatment plant) could be applied to agricultural land as a substitute for traditional chemical fertilizers. The following text documents results obtained during this three year Environment Canada study, coordinated by J.T.H. of Environmental Protection Saskatchewan District.

It has been theoretically shown that sludge from the Regina Wastewater Treatment Plant can be safely applied to agricultural land. The nutrient and trace element concentrations of Regina sludge are within the acceptable limits for use on agricultural land (Viraraghavan and Rana, 1987). Influent to the plant is continually monitored to prevent excessive quantities of metals and organic materials from being dumped into the treatment system. The intent of this study therefore, was to show that Regina City sludge could be applied to local agricultural land as a substitute for commercial fertilizers without detriment to the crop. It was to be demonstrated that a crop grown with either sludge or commercial fertilizer will exhibit similar protein content, trace metal content, magnitude of yield, and cost.

Sludge was taken directly from the Regina Municipal Sewage Treatment Plant and applied to agricultural land on three separate sites; site 1 beginning in 1987, and at sites 2 and 3 beginning in 1988.

2 METHODS

This study was undertaken to show that dewatered Regina Municipal sludge could be used as a substitute for commercial fertilizers. This was to be accomplished by growing a crop on sludged and chemically fertilized plots, and then showing that there was no significant difference in protein content and trace element concentrations of the two crops.

The demonstration was replicated on three separate plots of typical agricultural land. The three sites were sub-divided into control plots and plots which would receive sludge or fertilizer only. Sludge was applied to the land prior to seeding and fertilizer was applied according to the normal practice of the respective farmers. Typical crops were planted and then harvested as per normal practice. Samples of soils and sludge were tested for trace element and nutrient concentrations. Grains and vegetation were tested for trace element concentrations and protein content. Overall results of the lab analysis are presented in Appendices A through E.

2.1 Description of Study Area

The study area comprised three sites that were located on two agricultural farms within the general vicinity of the City of Regina (**Fig. 1, Fig. 2**).

Site 1 was established in 1987 on 4.80 ha. of stubble land 18km north of the Regina Sewage Treatment Plant (in the Rural Municipality of Lumsden). The site can be found by following Provincial Highway #6 north for 16 km out of Regina and travelling west for 9.6 km via grid road. The soil is of the **Regina Heavy Clay** association and textural type (Canada Land Inventory Map, 1959 assessment). The site was divided into six sub-plots as follows:

- Two, 0.5 ha. sludge plots, upon which dewatered sludge was applied.
- Two, 0.5 ha. control plots, upon which no sludge or fertilizer was applied.
- Two, 1.4 ha. fertilizer plots, upon which fertilizer was applied.

This site was divided into 2 effective study areas by a trail which bisected the site (**Fig. 2**). Different types of crops were usually grown on each side of the trail. The two sub areas are denoted as **Site 1 East**, and **Site 1 West**.

Site 2 was established in 1988 on the same farm as site 1. It occupied 4.90 ha. of summerfallow land located to the east of the first site (**Fig. 2**). This site was divided into two sub-plots; a 2.9 ha. sludge plot, and a 2.0 ha. control plot.

Site 3 was established in 1988 on 6.0 ha. of summerfallow land. It is located to the south of the Regina Sewage Treatment Plant in the Rural Municipality of Sherwood. The site can be found by following Dewdney Avenue west for 3 miles out of Regina. The soil is of the **Regina Heavy Clay** association and textural type (Canada Land Inventory Map, 1959 assessment). The site was divided into a sludge plot and a fertilized plot, each with an area of 3.0 ha..

Site 1 is level with relatively good drainage (Goalen and Harrison, 1989). All three sites are within the Dark Brown Soil Zone of Saskatchewan.

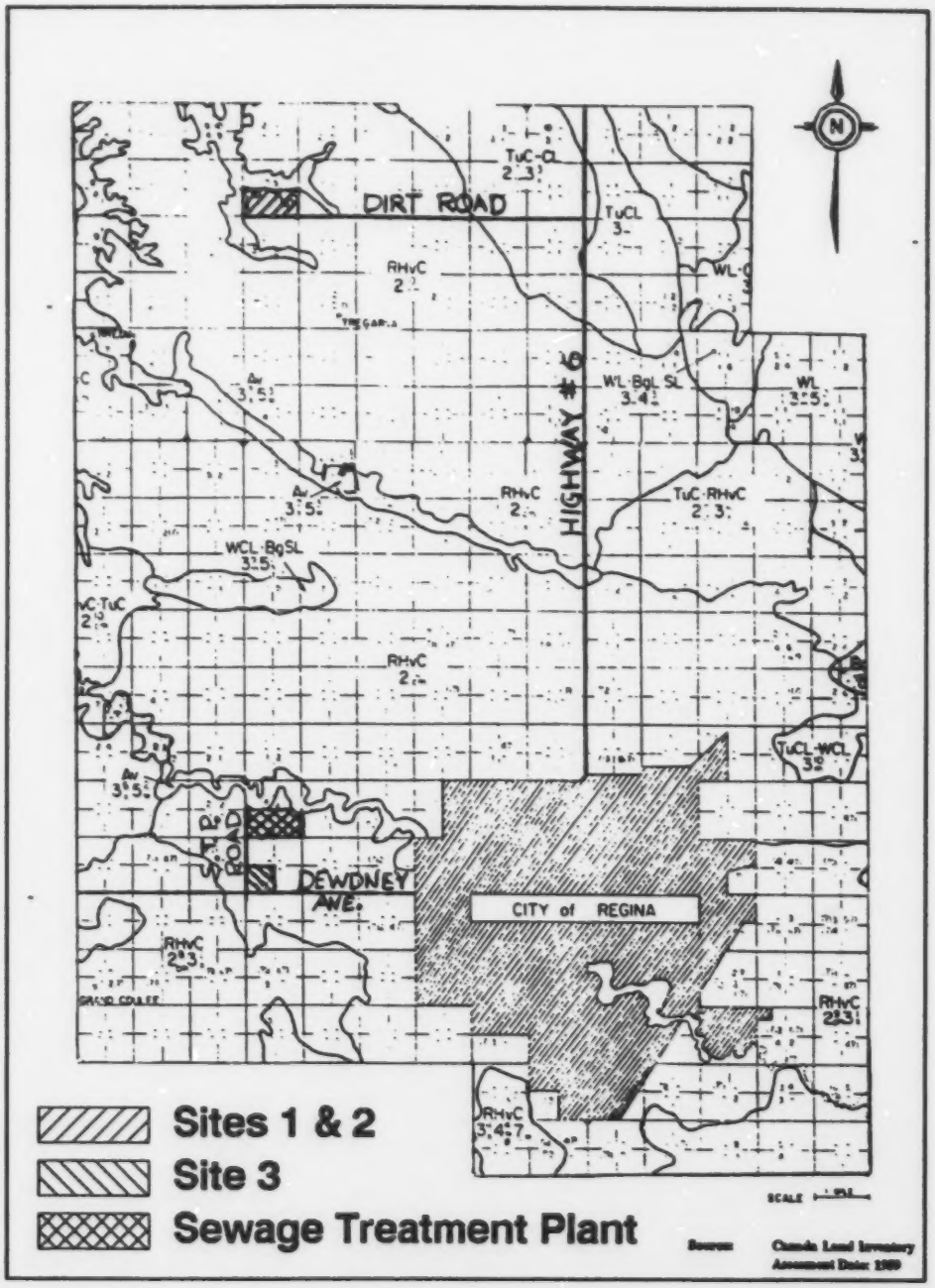

FIGURE 1
Study Area

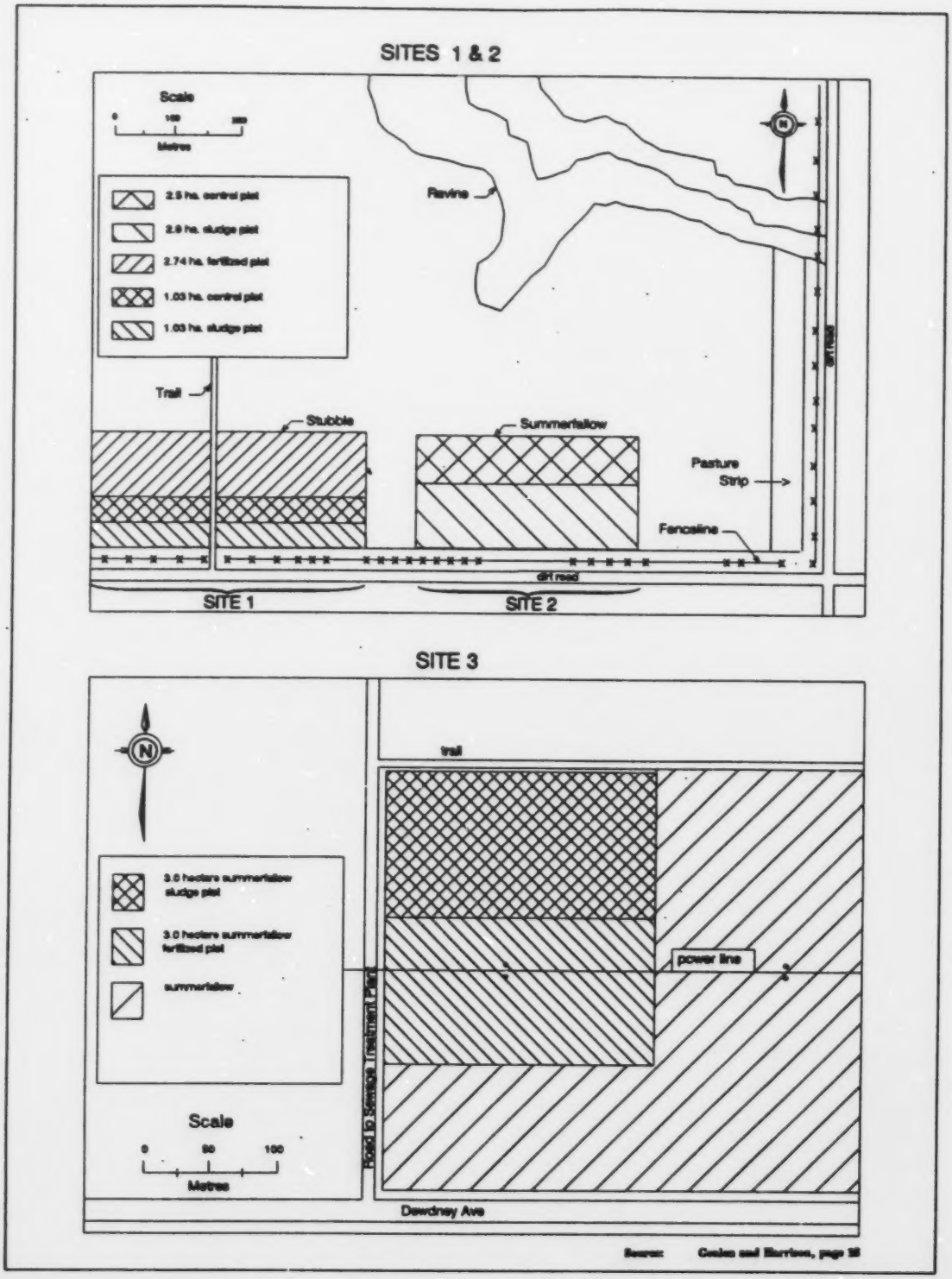

FIGURE 2
Layout of Sites 1, 2 and 3

2.2 Field Methods

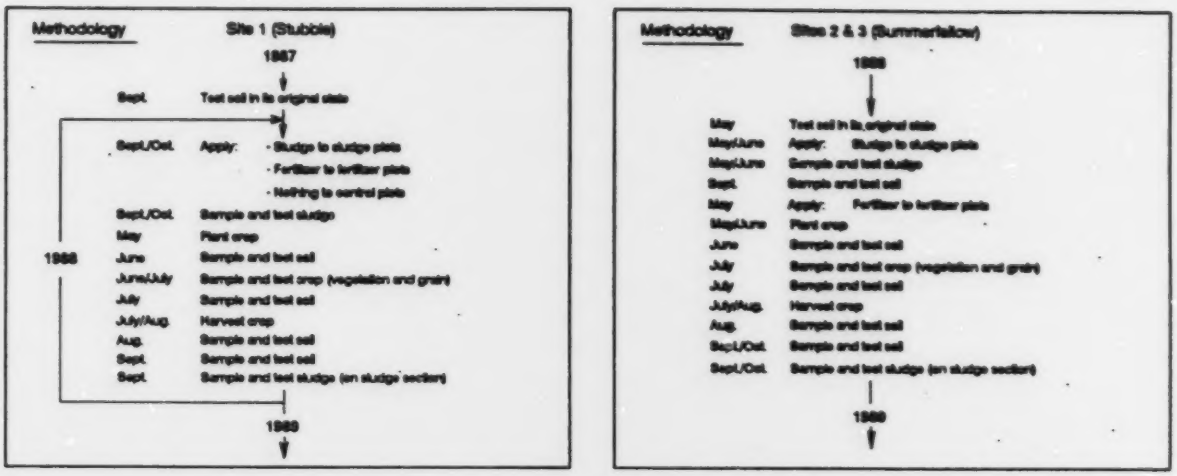

FIGURE 3
Field Methods - Sites 1, 2, and 3

2.2.1 Soil Sampling

Composite soil samples were collected as shown in Table 1. Individual samples were frozen until such time that they could be dried, mixed into composites, and a subsample sent to the Environmental Protection laboratory.

TABLE 1 - SOIL SAMPLING

DATE	LOCATION	SUBPLOT	SAMPLE DEPTHS (cm)	TYPE OF SAMPLER USED
September 1987	Site 1 E & W	Control Fertilized Sludged	0-15, 15-30, 30-60 " "	Truck Mounted Punch Corer
May 1988	Site 2	Control Sludged	0-30 "	Oakfield Sampler
	Site 3	Fertilized Sludged	0-30 "	Oakfield Sampler
June 1988	Site 1 E & W	Control Fertilized Sludged	0-30 " "	Oakfield Sampler

Continued.....

... TABLE 1 (continued) - SOIL SAMPLING

DATE	LOCATION	SUBPLOT	SAMPLE DEPTHS (cm)	TYPE OF SAMPLER USED
June 1988	Site 1 E & W	Control Fertilized Sludged	0-30 " "	Oakfield Sampler
July 1988	Site 1 E & W	Control Fertilized Sludged	0-30 " "	Oakfield Sampler
August 1988	Site 1 E & W	Control Fertilized Sludged	0-30 " "	Oakfield Sampler
	Soil samples were removed from freezer and spread on warehouse floor for drying. Dried samples were homogenized and then fractioned to reduce volume. Samples were then repackaged and placed back into the freezer.			
September 1988	Site 1 E & W	Control Fertilized Sludged	0-15, 15-30, 30-60 " "	Truck Mounted Punch Corer
	Site 2	Control Sludged	0-15, 15-30, 30-60 "	Truck Mounted Punch Corer
	Site 3	Fertilized Sludged	0-15, 15-30, 30-60 "	Truck Mounted Punch Corer
June 1989	Site 1 E & W	Control Fertilized Sludged	0-15 " "	Oakfield Sampler
	Site 2	Control Sludged	0-15 "	Oakfield Sampler
	Site 3	Fertilized Sludged	0-15 "	Oakfield Sampler
July 1989	Site 1 E & W	Control Fertilized Sludged	0-15 " "	Oakfield Sampler
	Site 2	Control Sludged	0-15 "	Oakfield Sampler
	Site 3	Fertilized Sludged	0-15 "	Oakfield Sampler
August 1989	Site 1 E & W	Control Fertilized Sludged	0-15 " "	Oakfield Sampler
	Site 2	Control Sludged	0-15 "	Oakfield Sampler
	Site 3	Fertilized Sludged	0-15 "	Oakfield Sampler

Continued.....

... TABLE 1 (continued) - SOIL SAMPLING				
DATE	LOCATION	SUBPLOT	SAMPLE DEPTHS (cm)	TYPE OF SAMPLER USED
September 1989	Site 1 E & W	Control Fertilized Sludged	0-15, 15-30, 30-60 " "	Truck Mounted Punch Corer
	Site 2	Control Sludged	0-15, 15-30, 30-60 "	Truck Mounted Punch Corer
October 1989	Site 3	Fertilized Sludged	0-15, 15-30, 30-60 "	Truck Mounted Punch Corer

The initial and final sets of samples that were collected at each of the three plots were tested for trace element and nutrient parameters. All other sets of samples were tested for nutrient parameters only.

2.2.2 Crop and Vegetation Sampling

Composite samples of crop foliage were collected immediately before the crops reached maturity (during June and July). Vegetation was cut at the ground using grass clippers. Samples were placed in plastic bags and frozen until they could be sent to the laboratory.

Grain samples were collected just before, or during harvest time (mid to late August).

TABLE 2 - CROP AND VEGETATION SAMPLING				
DATE	LOCATION	SUBPLOTS	SAMPLE TYPE	TYPE OF CROP
June 1988	Site 1 East	Control, Fertilized, Sludged	Vegetation	Spring Wheat
	Site 1 West	Control, Fertilized, Sludged	Vegetation	Durum Wheat
July 1988	Site 1 East	Control, Fertilized, Sludged	Vegetation	Spring Wheat
	Site 1 West	Control, Fertilized, Sludged	Vegetation	Durum Wheat
August 1988	Site 1 East	Control, Fertilized, Sludged	Grain	Spring Wheat
	Site 1 West	Control, Fertilized, Sludged	Grain	Durum Wheat

continued...

... TABLE 2 continued - CROP AND VEGETATION SAMPLING

DATE	LOCATION	SUBPLOTS	SAMPLE TYPE	TYPE OF CROP
July 1989	Site 1 East	Control, Fertilized, Sludged	Vegetation	Oats
	Site 1 West	Control, Fertilized, Sludged	Vegetation	Columbia Spring Wheat
	Site 2	Control, Sludged	Vegetation	Medora Durum Wheat
	Site 3	Fertilized, Sludged	Vegetation	Laura Spring Wheat
August 1989	Site 1 East	Control, Fertilized, Sludged	Grain	Oats
	Site 1 West	Control, Fertilized, Sludged	Grain	Columbia Spring Wheat
	Site 2	Control, Sludged	Grain	Medora Durum Wheat
	Site 3	Fertilized, Sludged	Grain	Laura Spring Wheat

2.2.3 Sludge Sampling

Composite samples of sludge were collected from the surface of sludged sub-plots. Samples were collected immediately after sludge was applied to the field, and within a month after harvest.

Samples of sludge were also collected at the Regina Sewage Treatment Plant at intermittent intervals.

2.2.4 Sludge Application

Dewatered municipal sludge was transported to the study areas with a dumptruck. The sludge was then applied to the sludged sub-plots with a manure spreader. The target rate of sludge application was 25 tonnes/ ha. The nitrogen content of the sludge, and the nitrogen requirement of the soil were compared and used as a guideline to determine an appropriate rate of sludge application.

After the sludge had been applied to the soil surface it was worked into the land using a discer, and in some instances a cultivator.

Sludge was applied to the designated sub-plots as shown in Table 3.

TABLE 3 - SLUDGE APPLICATION

DATE	SLUDGE PLOT LOCATION	TARGET RATE OF APPLICATION	ACTUAL RATE OF APPLICATION
October 1987	Site 1 East & West	25 tonnes / hectare	25 tonnes / hectare
May 1988	Site 2	26 tonnes / hectare	45 tonnes / hectare
June 1988	Site 3	25 tonnes / hectare	25 tonnes / hectare
September 1988	Site 1 East	25 tonnes / hectare	33 tonnes / hectare

2.2.5 Fertilizer Application

Fertilizers were applied to the designated sub-plots as shown in Table 4.

TABLE 4 - COMMERCIAL FERTILIZER APPLICATION

LOCATION	DATE	TYPE OF FERTILIZER	RATE OF APPLICATION	METHOD OF APPLICATION
Site 1 East & West	September 1987	34 - 17 - 0	100 lb/acre	Deep Banded
	May 1988	Not Available	Not Available	Deep Banded
	June 1989	34 - 17 - 0	Not Available	Deep Banded
Site 3	May 1989	11 - 51 - 0	40 to 50 lb/acre	Incorporated with a drill seeder while seeding

Fertilizer characteristics are presented in Appendix F.

2.2.6 Herbicide Application

Herbicides were applied to the study area as shown in Table 5.

TABLE 5 - HERBICIDE APPLICATION			
LOCATION	DATE	TYPE OF HERBICIDE	ACTIVE INGREDIENTS
Site 1 East & West	June 1988	Post Emergent Hoegrass	(Sethoxydim) (Diclofop-methyl)
East	1989	MCPA	(MCPA)
Site 2	1989	Avadex BW	(Triallate)
Site 3	1989	Refine'	(Thifensulfuron)

2.2.7 Seeding Methodology

Crops were planted in the study area as shown in Table 6.

TABLE 6 - CROP APPLICATION			
LOCATION	DATE	CROP	RATE OF APPLICATION
Site 1	1988	East - Spring Wheat West - Durum Wheat	90 - 120 lb / acre
	1989	East - Oats West - Columbia Spring Wheat	Not Available
Site 2	1989	Medora Durum Wheat	Not available
Site 3	1989	Laura Spring Wheat	40 lb / acre - Sludged plot 70 lb / acre - Fertilized Plot

2.2.8 Measurement of Crop Yields

No measurement was made of the crop yield in 1987 due to poor crop growth caused by drought.

Measurements of the crop yield in 1988 were made in the following fashion. All grain and vegetation was collected from a measured area of swath. The samples were then thrashed and the seeds were cleaned using a pair of screens. The finished samples of grain were then weighed.

During August 1989, the oats crop on the east side of the trail at site 1 was baled and counted. The bales were left on the appropriate sub-plots so that an accurate comparison of the respective yields could be made. Grain samples were taken from measured areas of standing crops at sites 2, 3 and the west side of site 1. The samples were then weighed and yield determinations were made.

2.3 Laboratory Methods

Laboratory analysis of soil, sludge, vegetation, and grain samples was performed by the Environmental Protection (Conservation and Protection) Analytical Services Laboratory in Edmonton, Alberta. Laboratory results were accompanied by quality control reports which provided detailed checks for precision and % recovery of trace elements and nutrients.

Some early analysis was carried out by the Saskatchewan Research Council. Those results however, were not used in conjunction with this report as there was considerable difficulty encountered in finding consistency with the results from the two laboratories.

Laboratory methodologies are presented in Appendix H.

2.4 Statistical Methods

Several statistical analysis were done to properly evaluate the results of laboratory analysis. Two sample "t" tests were used to evaluate the significance of the variation between means of sets of samples. The following null and alternative hypotheses were used:

$$H_0 : \overline{X}_1 = \overline{X}_2$$

$$H_a : \overline{X}_1 \neq \overline{X}_2$$

Comparisons that were made for each of the three plots were; sludged sub-plot vs. control, fertilized sub-plot vs. control, and sludged sub-plot vs. fertilized sub-plot.

3 RESULTS - DISCUSSION

Immediately after the initiation of this demonstration study, soil and sludge samples were analyzed for trace element and nutrient concentrations. The laboratory results indicated that the levels of trace elements in the soil and sludge were low and that the levels of trace elements in the sludge would not cause the overall levels in the soil to increase significantly (Goalen and Harrison, 1989). This conclusion is substantiated by the following analysis.

Table 7 summarizes the overall results of the demonstration study.

TABLE 7 - COMPARISON OF THE CHARACTERISTICS OF SLUDGED AND FERTILIZED PLOTS

CHARACTERISTIC	OVERALL RESULTS	
	SLUDGED PLOTS	FERTILIZED PLOTS
Crop Yield	· Similar yields for both types of sub-plot.	
Trace Element Concentrations (Grain and Vegetation)	· Higher concentrations of Zinc than found on Fertilized plots.	· Normal
Protein Content (Grain and Vegetation)	· Higher than Fertilized plots.	· Normal
Trace Element and Nutrient Concentrations (Soil)	· Overall, the concentrations for both types of sub-plot were comparable.	
Cost	· Less than Fertilized plots.	· Higher than Sludged plots

Analysis primarily centred upon site 1 as it was treated in the most consistent manner and was the focus of study for the longest period.

Site 2 was not concentrated upon as it had an excessive amount of sludge applied to it (excluding it from any comparisons due to inconsistent application) and there were no records kept regarding the rate of crop application. There was also no fertilized plot at site 2 that could be used for comparative purposes.

Site 3 was examined in a general fashion only, as there were not enough samples analyzed to make any proper statistical conclusions regarding the impact of sludge on the soils.

3.1 Crop Yield

Crop yield data from 1988 and 1989 are presented in Appendix A.

The 1988 crops at site 1 west showed similar yields for the sludge and fertilized sub-plots. Due to a poor yield from the sludged sub-plot at site 1 east, a positive conclusion could not be drawn regarding the crop performance in 1988. The low overall yield and high vegetative protein content of plant samples from site 1 east suggests that the yield was not restricted by poor nutrient conditions, but by some other factor. It could not be shown that the poor yield was related to the application of sludge. No statistical analysis was attempted for the 1988 yield since there was only one composite sample analyzed per sub-plot.

Yield data from 1989 showed no extreme values and yields were consistent for all sites. The sludged sub-plots at site 1 had higher yields than the fertilized sub-plots, and there was no significant difference between yields from the sludged and fertilized sub-plots at site 3. Note that there was no fertilized sub-plot at site 2.

The quantity of seed that was applied in 1989 to the fertilized sub-plot at site 3 was almost double that of the sludged sub-plot. This should provide an explanation for the slightly higher yield on the fertilized plot at this site only. No information was available regarding the rate of seed application to site 1 in 1989. In 1988, seed was applied to site 1 at a rate of 1.5 to 2.0 bushels per acre.

The results demonstrate that during the initial two years of application, sludged agricultural land can produce crops in quantities that are comparable to land which has been fertilized with a commercial nutrient supplement.

3.2 Grains

Data from the analysis of 1989 grain samples are presented in Appendix B.

A minimal number of samples from the August 1988 crop limited the degree of statistical analysis that could be performed. Qualitative inspection showed that the uptake of metals was comparable between sludged and fertilized sub-plots. Exceptions to this were demonstrated by concentrations of selenium and nickel that were higher in the sludged sub-plot than the fertilized sub-plot (east side of site 1). No comparisons could be made regarding aluminum, zinc, and iron concentrations.

Full statistical analysis was performed for samples that were collected in August 1989. With the exception of zinc, trace elements were not shown to be present in concentrations of any significant difference between the sludged or fertilized sub-plots. Concentrations of zinc and protein in samples from the sludged sub-plots were greater than samples from the fertilized sub-plots. Note that concentrations of zinc in the fertilized plots were less than those found in the control plots. As, Cd, Co, Hg, & Mo were present in unmeasurable (low) concentrations on all plots.

Grains that were grown on plots where sludge had been applied demonstrated higher protein contents than grains that were grown on the fertilized plots. Grain collected from sludged sub-plots showed the greatest mean protein content, and grain from the control plots showed the lowest.

3.3 Vegetation

Trace element uptake by vegetation was analyzed for samples from sludged and fertilized sub-plots only. The results of 1988 and 1989 lab analysis are presented in Appendix C. Note the lab analysis for 1988 and 1989 results are compared to the control.

Samples collected in June 1988 contained comparable levels of most trace elements. Concentrations of zinc and copper were noticeably higher in the sludged sub-plot (site 1). Outlying values were noted in data that was received from the lab (Cr, Al, B, Ni, Fe), but did not appear to have any significant impact on the analysis.

Samples collected in July 1988 contained comparable levels of trace elements with the exception of chromium and nickel which had concentrations in the east sludged plot that were lower than the fertilized (site 1), and aluminum, boron, copper and zinc in the west sludged plot that had concentrations that were greater than those found on the fertilized sub-plot. Most outlying values in the lab results (Al, B, Pb, Ni, Fe) occurred in data from the control plots. Outliers did not appear to have any impact on the analysis.

Vegetation from the west plots (site 1) had a significantly higher uptake of trace elements than the east plots (site 1). The west plot showed a higher protein content than the east, implying that the higher uptake of trace elements on the west plot was related to better growth.

Samples collected in 1989 contained comparable levels of trace elements. Exceptions to this were; concentrations of selenium in the east sludged plot were significantly lower than in the fertilized sub-plot (site 1), and concentrations of zinc in the east sludged plot were higher than in the fertilized sub-plot (site 1). There were no obvious outlying values among the results from the lab. Protein contents in both sludged plots at site 1 exceeded those found in the samples from the fertilized sub-plots, but there was no significant extra-uptake of metals.

Samples from the sludged sub-plots consistently contained greater quantities of zinc than samples from the fertilized sub-plots. An overall examination of the samples showed normal or sufficient concentrations of metals in all vegetative matter as defined by Pendias and Kabata-Pendias (Pendias and Kabata-Pendias, 1985). Note that As, Cd, Co, Hg, & Mo were present in unmeasurable (low) concentrations on all plots.

The protein content of samples from fertilized, sludged, and control sub-plots were analyzed and compared.

The protein content of samples collected during June 1988 showed no significant variation between any of the sub-plots. There was a slightly greater variation between the control and sludged sub-plots than there was between the fertilized and sludged sub-plots. Vegetation from

sub-plots where sludge was applied showed the greatest mean protein content, and vegetation collected from the control plots showed the lowest.

The protein content of vegetation collected during the months of July 1988 and July 1989 showed significant variation between sludged and fertilized sub-plots. Vegetation from sub-plots where sludge was applied showed the greatest mean protein content, while vegetation from the control plots showed the lowest.

The protein content of vegetation collected during the July 1988 and 1989 sampling showed significant variation between the sludged and fertilized sub-plots. No significant variation was found in samples that were collected during June. This anomaly implies that growth occurred the fastest in the sub-plots where sludge was applied and slowest in the control sub-plots.

3.4 Soil

The results of laboratory analysis for soil samples collected during September 1987, 1988, and 1989 are presented in Appendix D.

Two sample t-tests were done, comparing 1988 and 1989 soil analysis with background (September 1987) nutrient and trace element concentrations. Concentrations of trace elements and nutrients that were resident in the soils prior to sludge application (September 1987) were found to be normal with no obvious deficiencies or abundances. Analytical results from 1988 and 1989 for sludged and fertilized plots could not be directly compared using a t-test due to the minimal number of composite samples that were analyzed. Visual inspection of these results was sufficient for their overall interpretation.

In 1987, a reasonable number of samples (6) were available to allow for the naturally occurring variation of nutrient and trace element concentrations in soils. Only two composites per sub-plot from 1988 and 1989 were analyzed.

For the most part, the metal and nutrient content of soils from the study area demonstrated no discernible variation between any of the sub-plots. Total Extractable S, and Total Extractable P demonstrated higher concentrations in the sludged sub-plots than in the fertilized sub-plots. The variance could not be shown to be significant. "Excess P (in the soil) has no adverse effect on crops and can be used by future crops" (Goalen and Harrison, 1989). Levels of P should be expected to increase somewhat as crop requirements for P are not as significant as N, which the application rates were based upon. It should therefore be expected that the P content of the sludge would be in excess of the crops' requirements.

In 1988, there was a significant increase in nitrate (NO_3^-) nitrogen in the 0-15cm depth on the sludge plot at site 1. At all other sub-plots, NO_3^- levels in the 0-15cm strata did not change. NO_3^- concentrations in the 15-30cm and 30-60cm strata on all site 1 sub-plots were shown to be significantly lower than those of the background samples. At site 3, concentrations of ammonia (NH_3) nitrogen in the sludged plot appeared to be higher than that of the fertilized plot.

In 1989, there appeared to be a consistent decrease in nitrate and ammonia nitrogen levels on all site 3 sub-plots. There was also an indication that Cd and Cu levels on the sludged sub-plot may have been higher than those at the fertilized sub-plot. At site 1, concentrations of NO_3^--N, Cd, and Cr on all sub-plots were shown to be significantly lower than the 1987 background concentrations. Concentrations of As and Cu on control and fertilized sub-plots were significantly lower than the background levels. Cu concentrations at the sludged sub-plot were not found to be significantly higher than the background levels.

Although there was no significant increase in Cu levels at the sludged plots, the data did show an increase that was close to being significant. This implies that with the application of sludge, there may be a slow accumulation Cu in the soil. Soil should be monitored at 3 to 4 year intervals in order to precisely determine a quantitative rate of metal accumulation due to sludge application.

3.5 Sludge

The characteristics of Regina Municipal Sludge are presented in Appendix E.

The treatment process at the Regina Sewage Treatment Plant consists of aerated grit removal, primary clarification, anaerobic digestion, lagoon aeration, and tertiary clarification. Sludge is dewatered using belt presses.

Monitoring and analysis of sludge indicated no unusual or extreme levels of nutrients or trace elements during the period of study.

3.6 Analysis of Crop Available Nutrients From Sludge and Commercial Fertilizer Applications

In the Dark Brown soil zone of Saskatchewan nutrient deficiencies of phosphate and nitrogen are likely to occur (Nuttal et.al., 1985). There was an accumulation of phosphate in the soils in the sludged study area. Since phosphate is not generally a concern when found in abundance, it will not be necessary to discuss phosphate in any great detail.

Nitrogen bears discussion, as an excessive amount of nitrogen in soils can be a problem. When ammonium nitrogen is acted upon by the bacteria which reside in the soil, nitrate nitrogen is formed. While both nitrogen compounds are suitable as nitrogen sources for crops, nitrate nitrogen is not adsorbed by soil particles and will readily move downward as water percolates through the soil profile. The ammonium nitrogen either initially present in the sludge or released from organic nitrogen will be rapidly converted to nitrate nitrogen following the addition of sludge to the soil (U.S. Environmental Protection Agency, 1983).

It is therefore important to ensure that the amount of nitrogen applied to the soil does not significantly exceed the crops nutrient requirements. In order to estimate future application volumes of sludge it is necessary to calculate the effect of sludge applications on the quantity of usable nitrogen in the soil. This can be done by utilizing the US EPA formula which follows:

Calculation of Initial Annual Sludge Application Rates For nitrogen.
(U.S. Environmental Protection Agency, 1983)

$$N_p = S[NO_3 + K_V(NH_4) + F_{(year\,0\text{-}1)}(N_o)]$$

Where:

Np = Plant available N from this years' application only, in Kg/ha.

S = Sludge application rate, in dry tonnes/ha.

NO_3 = Percent nitrate-N in the sludge, as percent (e.g., 1% = 1.0).

Kv = Volatilization factor = 0.5 for surface-applied liquid sludge, or 1.0 for incorporated liquid sludge and dewatered sludge applied in any manner.

NH_4 = Percent ammonia-N in the sludge, as percent (e.g., 2% = 2.0).

$F_{(year\ 0\text{-}1)}$ = Mineralization factor for organic N in the sludge in the first year (from Table 6-7), expressed as a fraction (e.g., 20% = .2). Note that F becomes constant after year 4.

Year	F
0-1	0.20
1-2	0.10
2-3	0.05
3-4	0.03
4-5	0.03

N_O = Percent organic N in the Sludge, as percent (e.g., 3% = 3.0)

This formula is used to calculate the additional crop available nitrogen which becomes accessible in the soil due to a sludge application and the subsequent nitrogen interaction with crops (Tables 28 & 30, Appendix G). Note that an application of sludge results in a slow release of crop available nitrogen as the organic nitrogen content of the sludge mineralizes.

In order to appreciate the relationship between the crop uptake of nitrogen, and the nitrogen which is made available to crops via sludge application, it was necessary to calculate the crop uptake of nitrogen. This was done by taking the measured crop yields and calculating uptake of nitrogen based on crop requirements that were published by the Saskatchewan Advisory Council on Soils and Agronomy (Nuttal et.al., 1985).

For example, a wheat crop with a 2690 kg/ha yield will require 95 kg/ha of nitrogen. An oats

crop with a 3046 kg/ha yield will require 94 kg/ha of nitrogen (Nuttal et.al., 1985). Assuming that the relationship between the magnitude of yield and nitrogen requirement is essentially linear, the nitrogen uptake can be calculated based upon a given yield for a crop.

There was no indication of increases in nitrate concentrations in the lower strata of the soil as would be expected if nitrate were to leach toward the water table. This is somewhat inconclusive however, as there is no way of knowing how rapidly the leachate moves or at what strata an accumulation would be likely to occur. No information regarding the local water table was obtained during the study and therefore no conclusions should be drawn regarding the impact of the sludge on the water table until more thorough investigation ensues.

Crop available nitrogen resulting from sludge and fertilizer applications are presented in Appendix G. Calculations (Table 30) showed that there were no increases in levels of crop available nitrogen in the soils resulting from the application of sludge. This is consistent with laboratory and statistical analyses (Appendix D) which show no increases in nitrogen levels in the soils. Note that for the data presented in Appendix G, it was assumed that there was no leaching of nitrate nitrogen as data was insufficient to provide any conception as to how nitrate movement occurred through the soils within the study area. This information should be determined should one wish to show the extent to which groundwater will be affected by sludge application.

Overall, although an excessive quantity of sludge was applied to site 2 in 1989, calculations showed that crop available nitrogen was not applied in excess of crop requirements on any of the sludged or fertilized sub-plots.

3.7 Economic Evaluation - Sludge vs. Fertilizer Application

The overall costs associated with the application of sludge and commercial fertilizers were calculated and compared. Calculations were based upon the cost of the nutrient supplement that was to be applied, the cost of transportation to the point of application, and the cost of application to the land. Costs are presented as cost per year, and are in constant dollars. The following assumptions were made:

- The City of Regina absorbed the cost of transporting the sludge to the farm sites since it would have had to transport the sludge to the municipal landfill for disposal anyway. sites 1 and 2 are approximately 18km due north of the sewage treatment plant and site 3 is 2.6km. The distance from the treatment plant to the municipal landfill is 21.7km.

- The City of Regina absorbs the cost of at-source sludge testing / monitoring as it is a matter of regular procedure at the sewage treatment plant.

- The City of Regina did not charge the farmers for the cost of the sludge.

- Soil samples are taken from each sludged farm site at four year intervals in order to test

for trace element and nutrient accumulations. The cost of analysis is assumed to be $98 per sample

- The cost of transporting the chemical fertilizer is $20/tonne/20km haul, or roughly $0.19/ha.

- Soil samples are collected and tested for nutrient parameters once per year from chemically fertilized sites. The cost of analysis is $19 per year according to Saskatoon Soil Testing Labs at the University of Saskatchewan.

- The cost for soil sample collection is not included in the analysis as it is assumed to be the same for all sites.

- The costs presented below were calculated for fields with a base area of 1/4 section (64.75 ha).

- The typical rate of sludge application to agricultural land is 25 tonne/ha.

- It costs the City of Regina $10.80/tonne to landfill sludge.

- The typical costs of commercial chemical fertilizers are calculated as follows:

Type of Fertilizer	Typical Rate of Application (Kg/ha)	Cost ($/Kg)	Cost ($/ha)
34-17-0	89.3	0.26	23.22
11-51-0	35.7	0.31	11.07

(Source: Conversation with fertilizer suppliers, March 1992)

- The costs of the pre-application storage of sludge and commercial fertilizer were not considered.

- Sludge was applied at a rate of 1 hectare per hour.

Calculations were based upon normal rates of application and the characteristics of chemical fertilizers that were normally used by the farmers who were involved with this study. Note that all costs are based on 1992 prices.

TABLE 8 - CALCULATION OF COSTS OF SLUDGE AND CHEMICAL FERTILIZER APPLICATION							
Activity	Equipment	Cost ($/hr)	Time Used (hr)	Area (ha)	Custom Rate ($/acre)	Cost ($/ha)	Total ($/ha)
SLUDGE APPLICATION							
Sludge Loading into Manure Spreader	Front End Loader	37.72	0.5	2.9		6.50	
Sludge Application *	Manure Spreader and Tractor	80.00	3.0	2.9		82.76	
Integration of Sludge into Soil	Discer		0.71	2.9	6.40	15.82	
	100hp 4WD Tractor	51.43	0.71	2.9		12.59	117.67
34-17-0 APPLICATION (Solid)							
Bulk Application	Bulk Fertilizer Spreader				1.82	4.50	
	100hp 4WD Tractor	51.43	0.42	4.1		5.27	
Integration of Fertilizer into Soil	Discer		1.0	4.1	6.40	15.82	
	100hp 4WD Tractor	51.43	1.0	4.1		12.54	38.13
11-51-0 APPLICATION (Solid)							
Fertilizer Application and Integration into Soil	Discer with Fertilizer Att.				6.36	15.72	
	100hp 4WD Tractor	51.43	1.0	5.26		9.78	25.50

(Saskatchewan Agriculture and Food, 1992 Farm Machinery Custom and Rental Rate Guide.)
*(Sludge Rates from conversation with custom contractor.)

TABLE 9 - COST COMPARISON OF SLUDGE VS CHEMICAL FERTILIZER APPLICATION						
Type of Application	Fertilizer ($/ha)	Transportation ($/ha)	Application ($/ha)	Soil Testing ($/field)	Cost to Farmer ($/ha)	Cost to City for Disposal of Sludge ($/ha)
COST OF SLUDGE APPLICATION						
Sludge	0	0	117.67	24.50	118.04	0
COST OF CHEMICAL FERTILIZER APPLICATION						
34-17-0	23.22	0.19	38.13	19.00	61.82	270.00
11-51-0	11.07	0.19	25.50	19.00	37.04	270.00

(note: 64.75 ha (160 acres) = 1/4 Section)

The cost of applying sludge to a field is higher than that for chemical fertilizers, due to the high cost for the application. The cost of application of sludge, not including integration into the soil, is over 9 times the cost of applying a commercial fertilizer. This is due to the relatively slow rate of application; 1 hectare per hour for a manure spreader, compared with 9.7 hectares per hour for a bulk fertilizer applicator. Note that the savings to the city would also be significant as it would save $17,500 on disposal costs by supplying sludge for a 1/4 Section field. If the city were to apply some of the savings towards the cost of sludge application, the costs to the farmer could be reduced significantly. For example, if the city were to cover the entire cost of sludge application for the farmer, the city would still find a savings of $150 per hectare associated with the agricultural disposal of sludge.

The sewage treatment plant produces 8.6 tonnes of sludge per day (260 tonnes/month) (City of Regina, unpublished information). This means that it would take 6.2 months to produce the 1620 tonnes of sludge required for a 1/4 section of land . Since the time of year when sludge can be applied to land is relatively short, it would be necessary for either the City of Regina or the farmer to stockpile sludge in a fashion that would not cause any reduction of the nutrient concentrations. The cost of stockpiling sludge should be carefully compared with that of landfilling the sludge. There can be odour problems associated with sludge stockpiles and this should be considered before any stockpiling effort is implemented. Note that damage to the environment will occur, such as the leaching of wastes to groundwater. Costs associated with this kind of environmental damage have not been taken into account in the above calculations.

3.8 Errors, Omissions, and Comments

No comparisons of vegetation, yield, grain, or soil were made between the three sites. All comparisons were limited to the sub-plots at each individual site. Since the crops and applications to the fields were not consistent between sites, any cross comparison of data between different sites would not likely have been reliable. It was necessary to keep averages consistent and to ensure that the quantity of data from sub-plots where sludge was applied did not exceed the information derived from any of the other type of sub-plot.

In some instances, outlying (extreme) values were apparent in the data that was presented in the lab results. While they did not seem to have any significant effect on the outcome of analysis, the extremes have been outlined on the data sheets where they occur.

The sampling methodology used for this study was in some instances excessive. The collection of soil samples should have been limited to the late fall since this provides the most reliable measurements for nutrients (Nuttall, et al., 1985) and analysis was limited to an annual basis anyway.

Sampling of vegetation could have been limited to collection at the time of plant maturity only. Dividing sampled material into a greater number of duplicates would have provided a much greater quantity of usable information, and allowed better interpretation of the lab results.

Although there were no immediate or apparent adverse effects resulting from the excessive application of sludge to site 3, it should be noted that sludge should be applied in as precise a fashion as possible. Over-application could cause problems if not compensated for in future applications of sludge or fertilizer. "(Excessive) sludge application may disrupt crop production. This may be reflected by reduced growth, delayed maturity, lodging [resulting from stem weakness or breakage] and reduced crop quality." (Black et.al., 1984). "To avoid groundwater contamination, the plant available nitrogen content in the sludge should not significantly exceed the crop requirement." (Black et.al., 1984). If at all possible, the nutrient losses due to volatilization to the atmosphere and leaching should be calculated and accounted for prior to the application of sludge. The immediate and long term effects of over-application are not desirable and care should be taken so that it does not occur.

It was observed that after the sludge had been disced into the soil, sludge clumps continued to persist on the surface at some locations for periods of up to a year or more. This problem might be rectified by injecting liquid sludge directly into the soil, or by more comprehensive discing or plowing after surface application.

4 CONCLUSIONS

Agricultural land in the Regina area received treated sludge from the Regina Sewage Treatment Plant, and produced crops that were comparable to those produced on land that was fertilized with commercial nutrient supplements.

The performances of all of the various crops were satisfactory. General analysis suggested that sludged plots may have performed slightly better than fertilized plots, but any difference was small enough that it could not be considered significant.

There were no abnormal concentrations of trace elements found in any of the crops that were grown on land where sludge was applied. There were no detrimental effects on the soil that could be attributed to the application of sludge.

In general, the soils on the sludged plots showed no significant elevations in the levels of trace elements. The control and fertilized plots however, showed significantly lower concentrations of copper. The copper concentration in soil from sludged plots was not significantly higher than background levels although it was close to being so. Viraraghavan and Rana (Viraraghavan and Rana, 1987) identified Cu as the element which would be the limiting factor to total sludge application at a quantity of 87 tons of sludge per acre (195 tonnes per hectare). "Copper exhibits limited translocation and seldom occurs at concentrations greater than 20 mg/Kg dry weight in above-ground plant material." (Black et.al., 1984).

Vegetation from the sludged plots showed significantly higher concentrations of zinc when compared to levels on fertilized and control plots, but this was not indicative of any abnormal increases in Zn concentrations. Even if Zn levels in the plant material were shown to be elevated, Zn is not usually a health concern as Zn is a normal part of the human diet and chronic zinc poisoning to humans has not been reported (Black et.al., 1984).

The protein content of grain and vegetative matter from sludged land was consistent with that from the fertilized and control plots, and in some cases significantly higher.

It was shown that with assistance from the City, an operation utilizing large scale application of sludge (per $^1/_4$ section) would be more cost effective than a similar operation using a commercial fertilizer.

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APPENDIX A
YIELD DATA

Note: All calculations done on Lotus, therefore there may be slight differences from manual calculations.

TABLE 10
1988 Crop Yields

Site	Sub – plot	Crop	Grain Weight (g)	Swath Area (m ^ 2)	Yield (kg/ha)	Yield (bu/Ac)	Yield divided by Control Yield	Provincial Yield Averages (bu/Ac)
1 West	Control	Durum	129.5	11.2	115.6	1.7	1.0	11.3
	Fertilizer		470	11.8	398.3	5.9	3.4	
	Sludge		339	11.2	302.7	4.5	2.6	
1 East	Control	Spring Wheat	424	11.2	378.6	5.6	1.0	13.7
	Fertilizer		557	11	506.4	7.5	1.3	
	Sludge		67	11.8	56.8	0.8	0.1	

(Source, Provincial Averages: Saskatchewan Agriculture Economics Branch)

TABLE 11
1989 Crop Yields

Site	Sub – plot	Crop	Grain Weight (kg)	Measured Area (m ^ 2)	Yield (kg/ha)	Yield (bu/Ac)	Yield divided by Control Yield	Provincial Yield Averages (bu/Ac)
1 West	Control	Columbia Spring Wheat	11.4	189.5	602.6	8.9	1.0	23.9
	Fertilizer		10.3	185.8	556.2	8.3	0.9	
	Sludge		15.2	197.0	773.4	11.5	1.3	
1 East	Control	Oats	Yield was measured in bales for Oats crop.		38.0	bales	1.0	43.3
	Fertilizer				50.0	bales	1.3	
	Sludge				53.0	bales	1.4	
2	Control	Medora Durum	15.2	130.1	1167.5	17.3	1.0	36.7
	Sludge		19.4	122.8	1580.3	23.5	1.4	
3	Fertilizer	Laura Spring Wheat	14.1	74.3	1900.8	28.2	1.0	23.9
	Sludge		10.4	74.3	1398.8	20.7	0.7	

2
10,000 m = 1 ha

1.123 kg/ha = 1.0 lb/acre

1 bushel = 60 lb

(Source, Provincial Averages: Saskatchewan Agriculture Economics Branch)

TABLE 12
1989 Crop Yields – t tests

Site	Crop	Control plot			Fertilized plot			Sludge plot			Comparison	S_c^2	t
		Grain Weight (Kg)	Area (m^2)	Yield (bu/Ac)	Grain Weight (Kg)	Area (m^2)	Yield (bu/Ac)	Grain Weight (Kg)	Area (m^2)	Yield (bu/Ac)			
1 West	Columbia Spring Wheat	1.38	18.95	10.82	0.77	18.58	6.13	1.43	19.70	10.75	Sludge vs. Control	3.01	1.88
		1.40	18.95	10.96	1.00	18.58	7.99	1.06	19.70	8.17			
		1.24	18.95	9.73	1.13	18.58	9.03	1.43	19.70	10.74			
		1.22	18.95	9.56	1.09	18.58	8.70	1.64	19.70	12.38			
		1.04	18.95	8.14	1.17	18.58	9.35	2.03	19.70	15.30			
		1.12	18.95	8.73	0.92	18.58	7.37	1.38	19.70	10.40	Fert. vs. Control	1.54	1.00
		0.93	18.95	7.27	0.92	18.58	7.37	1.49	19.70	11.24			
		0.89	18.95	6.95	0.97	18.58	7.76	1.27	19.70	9.58			
		1.05	18.95	8.22	1.20	18.58	9.58	1.73	19.70	13.06			
		1.15	18.95	9.03	1.16	18.58	9.27	1.75	19.70	13.17	Sludge vs. Fert.	2.71	2.66
		Mean		8.94	Mean		8.26	Mean		11.46			
1 East	Oats	Yeild was measured in bales for Oats crop.		38.00 (bales)			50.00 (bales)			53.00 (bales)	Yeild: Sludge > Fert. > Control		
2	Medora Durum	1.56	13.01	16.06				1.88	12.26	22.73	Sludge vs. Control	13.04	1.05
		1.22	13.01	13.96				1.33	12.26	16.10			
		1.62	13.01	18.50				2.18	12.26	26.36			
		1.06	13.01	12.12				2.23	12.26	27.04			
		1.54	13.01	17.60				2.39	12.26	28.92			
		2.08	13.01	23.72				1.70	12.26	20.53	Fert. vs. Control		
		1.44	13.01	16.46				1.74	12.26	21.00			
		1.68	13.01	19.16				2.06	12.26	24.87			
		1.77	13.01	20.15				1.82	12.26	22.03			
		1.19	13.01	13.53				2.06	12.26	24.86	Sludge vs. Fert.		
		Mean		17.33	Mean			Mean		23.45			
3	Laura Spring Wheat				1.40	7.43	27.88	0.97	7.43	19.33	Sludge vs. Control		
					1.43	7.43	28.54	0.90	7.43	17.97			
					1.53	7.43	30.63	1.00	7.43	19.97			
					1.57	7.43	31.43	0.98	7.43	19.55			
					1.46	7.43	29.13	0.92	7.43	18.39			
					1.20	7.43	23.94	0.89	7.43	17.75	Fert. vs. Control		
					1.41	7.43	28.16	0.87	7.43	17.33			
					1.39	7.43	27.72	1.03	7.43	20.59			
					1.25	7.43	25.00	1.40	7.43	27.90			
					1.49	7.43	29.65	1.43	7.43	26.52	Sludge vs. Fert.	10.96	1.52
		Mean			Mean		28.21	Mean		20.73			

S_c^2

10,000 m^2 = 1 ha 1.123 kg/ha = 1.0 lb/acre 1 bushel = 60 lb

$H_0 : \bar{X}_1 = \bar{X}_2$ $H_a : \bar{X}_1 <> \bar{X}_2$

At the 95% level of confidence, t = 2.101

APPENDIX B
GRAIN DATA

Note: All calculations done on Lotus, therefore there may be slight differences from manual calculations.

TABLE 13
1989 Grain Samples – Protein Content & Trace Element Concentrations

Grain samples
Aug 1989

Concentration
(ug/g unless specified)

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 West	15.10		< 0.05	4.20	< 0.40	< 0.80	1.10	4.50	8.80	< 0.04	1.50	4.10	0.70	39.00	
	1 East	15.00		< 0.05	2.40	< 0.40	< 0.80	0.80	4.30	9.10	< 0.04	< 1.00	2.20	0.80	36.10	
	2	12.70		< 0.05	3.70	< 0.40	< 0.80	0.80	4.40	13.80	< 0.04	< 1.00	1.00	1.10	32.90	
	3	12.50		< 0.05	20.70	< 0.40	< 0.80	0.80	4.20	11.10	< 0.04	< 1.00	2.20	1.00	33.90	
Fertilized	1 West	16.50		< 0.05	5.30	< 0.40	< 0.80	0.80	4.70	12.30	< 0.04	< 1.00	3.40	0.80	25.30	
	1 East	16.30		< 0.05	7.80	< 0.40	< 0.80	0.80	4.40	10.40	< 0.04	< 1.00	1.00	0.40	24.60	
	2															
	3	12.00		< 0.05	26.40	< 0.40	< 0.80	1.20	4.80	8.20	< 0.04	1.10	5.10	0.30	32.80	
		13.20		< 0.05	8.50	< 0.40	< 0.80	0.80	4.90	8.40	< 0.04	< 1.00	2.90	0.30	33.80	
Sludge	1 West	19.50		< 0.05	12.30	< 0.40	< 0.80	0.80	5.00	7.90	< 0.04	< 1.00	2.80	0.50	30.80	
	1 East	19.80		< 0.05	48.00	< 0.40	< 0.80	0.80	5.20	9.80	< 0.04	< 1.00	3.90	0.80	38.00	
	2	13.00		< 0.05	4.80	< 0.40	< 0.80	0.80	4.40	10.00	< 0.04	< 1.00	3.90	0.50	34.70	
	3	13.20		< 0.05	23.90	< 0.40	< 0.80	1.20	4.40	17.30	< 0.04	< 1.00	2.80	0.40	33.80	
		13.70		< 0.05	6.90	< 0.40	< 0.80	0.80	5.00	7.20	< 0.04	< 1.00	1.00	0.40	22.10	
		13.40		< 0.05	4.00	< 0.40	< 0.80	1.10	5.40	11.20	< 0.04	< 1.00	2.20	0.40	24.30	

TABLE 14
1989 Grain Samples – t tests

Grain samples
Aug 1989

Two sample "t" test

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	29.98			2.11			1.00	0.83	2.50		1.00	0.62	1.34	6.45	
	1 East															
	2															
"t"	3															
Sludge vs. Control	1 West	29.09			1.53			1.00	4.95	0.23		1.00	0.08	1.41	1.39	
	1 East															
	2	3.54			0.15			1.00	1.00	0.29			1.93	8.49	0.10	
"t"	3															
Sludge vs. Fertilized	1 West	6.93			1.34				3.05	1.82			0.77	0.45	3.22	
	1 East															
	2															
"t"	3	1.54			1.46			0.47	1.70	0.45		1.00	1.82		8.36	

At the 90% level of confidence, t = 2.920

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad H : \bar{X}_1 <> \bar{X}_2$

$t = | \bar{X}_1 - \bar{X}_2 | / (Sc * (.5 + .5)\,\hat{}\,2)$

Calculation of Sc

Grain samples
Aug 1989

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	0.11		0.00	1.54	0.00	0.00	0.15	0.18	0.98	0.00	0.25	1.53	0.11	1.49	
	1 East															
	2															
	3															
Sludge vs. Control	1 West	0.16		0.00	16.87	0.00	0.00	0.15	0.14	1.11	0.00	0.25	1.15	0.07	2.98	
	1 East															
	2	0.14		0.00	12.64	0.00	0.00	0.20	0.10	3.91	0.00	0.00	0.75	0.07	1.57	
	3															
Sludge vs. Fertilized	1 West	0.18		0.00	16.90	0.00	0.00	0.00	0.18	1.45	0.00	0.00	1.38	0.11	2.62	
	1 East															
	2															
	3	0.62		0.00	8.57	0.00	0.00	0.21	0.21	2.00	0.00	0.05	1.38	0.00	1.21	

$Sc = ((\text{sum}_1 ((X_1 - \bar{X}_1)\,\hat{}\,2) + \text{sum}_2 ((X_2 - \bar{X}_2)\,\hat{}\,2)) / (2 + 2 - 2))\,\hat{}\,0.5$

APPENDIX C
VEGETATION DATA

Note: All calculations done on Lotus, therefore there may be slight differences from manual calculations

TABLE 15
June 1988 Vegetation Samples – Protein Content & Trace Element Concentrations

Vegetation samples
June 1988

Concentration
(ug/g unless specified)

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 West	26.70	418.00	0.24	7.16	< 0.40	< 0.60	19.30	8.66	< 6.00	< 0.04	< 1.00	1.73	1.16	41.10	390.00
	1 East	19.10	317.00	0.19	4.79	< 0.40	< 0.60	0.80	7.94	< 6.00	< 0.04	< 1.00	2.64	0.92	37.30	290.00
	2	17.80	429.00	0.25	4.24	< 0.40	< 0.60	0.80	6.84	< 6.00	< 0.04	< 1.00	2.58	1.14	35.20	395.00
	3	18.60	560.00	0.29	12.50	< 0.40	< 0.60	3.22	6.20	< 6.00	< 0.04	< 1.00	7.40	0.88	30.30	530.00
	mean	20.55	431.00	0.24	7.17	< 0.40	< 0.60	6.03	7.46	< 6.00	< 0.04	< 1.00	3.58	1.03	35.98	401.25

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 West	18.50	233.00	0.10	4.74	< 0.40	< 0.60	0.80	6.47	< 6.00	< 0.04	< 1.00	4.10	1.30	26.80	218.00
	1 East	21.10	1153.00	0.44	5.70	< 0.40	< 0.60	3.17	8.08	< 6.00	< 0.04	< 1.00	3.10	0.83	30.80	1128.00
	2	19.10	211.00	0.20	3.66	< 0.40	< 0.60	2.25	6.27	< 6.00	< 0.04	< 1.00	5.39	1.16	29.00	227.00
	3	22.00	273.00	0.15	19.70	< 0.40	< 0.60	2.34	7.28	< 6.00	< 0.04	< 1.00	4.69	1.66	31.80	257.00
	mean	20.18	467.50	0.22	8.46	< 0.40	< 0.60	2.14	7.03	< 6.00	< 0.04	< 1.00	4.32	1.24	29.60	457.50

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 West	21.00	299.00	0.15	7.29	< 0.40	< 0.60	0.80	7.74	< 6.00	< 0.04	< 1.00	2.53	1.47	39.80	276.00
	1 East	23.30	497.00	0.22	2.38	< 0.40	< 0.60	2.47	7.91	< 6.00	< 0.04	< 1.00	2.22	0.88	38.80	482.00
	2	24.90	281.00	0.18	7.01	< 0.40	< 0.60	3.58	9.24	< 6.00	< 0.04	< 1.00	2.71	1.33	37.60	298.00
	3	19.20	217.00	0.15	8.29	< 0.40	< 0.60	1.43	10.30	7.37	< 0.04	< 1.00	16.80	0.96	41.50	283.00
	mean	22.10	323.50	0.18	6.24	< 0.40	< 0.60	2.07	8.80	< 6.34	< 0.04	< 1.00	6.07	1.16	38.93	329.75

[ ] Indicates an outlier

TABLE 16
June 1988 Vegetation Samples – t tests

Vegetation samples
June 1988

Two sample 'T' test

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	0.77	0.70	0.32	0.59			0.86	1.21				2.09	0.06	3.77	0.73
	1 East	1.56	3.48	2.97	0.37			0.24	0.43				0.02	1.42	0.83	3.19
T	2															
	3															
Sludge vs. Control	1 West	0.19	0.27	0.70	0.42			0.91	1.23				0.40	0.39	0.37	0.34
	1 East	1.34	3.37	4.20	0.17			0.31	5.25	1.00			0.64	0.60	2.17	2.61
T	2															
	3															
Sludge vs. Fertilized	1 West	1.35	0.63	0.49	0.15			0.24	0.68				2.34	0.29	3.80	0.83
	1 East	0.47	0.16	0.34	0.50			0.20	4.09	1.00			0.67	0.85	3.81	1.67
T	2															
	3															

At the 90% level of confidence, t = 2.920

$$t = |\bar{X}_1 - \bar{X}_2| / (Sc * (.5 + .5)^{\wedge} 2)$$

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad$ $H_a : \bar{X}_1 <> \bar{X}_2$

Calculation of Sc

Vegetation samples
June 1988

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	4.02	462.76	0.17	1.28	0.00	0.00	9.33	0.93	0.00	0.00	0.00	0.68	0.27	2.76	457.74
	1 East	1.50	72.47	0.03	9.01	0.00	0.00	1.21	0.60	0.00	0.00	0.00	2.45	0.28	2.82	68.15
	2															
	3															
Sludge vs. Control	1 West	3.97	111.14	0.04	2.73	0.00	0.00	9.29	0.47	0.00	0.00	0.00	0.48	0.32	2.42	114.49
	1 East	2.86	72.90	0.03	4.18	0.00	0.00	1.62	0.62	0.69	0.00	0.00	7.45	0.23	3.13	69.73
	2															
	3															
Sludge vs. Fertilized	1 West	1.74	470.53	0.17	2.50	0.00	0.00	1.45	0.61	0.00	0.00	0.00	0.52	0.38	2.50	466.51
	1 East	3.20	44.66	0.03	8.04	0.00	0.00	1.08	0.73	0.69	0.00	0.00	7.06	0.31	2.40	22.06
	2															
	3															

$$Sc = ((\text{sum}((X_1 - \bar{X}_1)^{\wedge} 2) + \text{sum}((X_2 - \bar{X}_2)^{\wedge} 2)) / (2 + 2 - 2))^{\wedge} 0.5$$

TABLE 17
July 1988 Vegetation Samples – Protein Content & Trace Element Concentrations

Vegetation samples July 1988

Concentration (µg/g unless specified)

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 West	12.00	[1390.00]	0.04	2.49	< 0.40	< 0.60	3.24	5.50	6.00	< 0.04	< 1.00	4.48	0.76	44.50	[1390.00]
		11.80	352.00	0.20	5.32	< 0.40	< 0.60	2.33	4.01	6.00	< 0.04	< 1.00	1.56	0.76	39.00	357.00
	1 East	10.20	116.00	0.08	2.96	< 0.40	< 0.60	3.61	3.62	14.00	< 0.04	< 1.00	4.30	1.30	26.30	137.00
		10.20	126.00	0.12	[20.30]	< 0.40	< 0.60	4.68	3.67	[34.20]	< 0.04	< 1.00	[17.60]	1.37	29.40	145.00
	2															
	3															
	mean	11.05	496.00	0.26	7.77	< 0.40	< 0.60	3.52	4.25	15.05	< 0.04	< 1.00	6.99	1.05	34.80	509.50

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 West	10.30	104.00	0.14	4.29	< 0.40	< 0.60	5.16	3.69	21.50	< 0.04	< 1.00	4.36	0.75	28.70	127.00
		11.40	100.00	0.12	3.05	< 0.40	< 0.60	4.20	4.41	37.60	< 0.04	< 1.00	[10.20]	0.60	25.40	127.00
	1 East	12.80	132.00	0.23	5.47	< 0.40	< 0.60	3.62	4.46	8.77	< 0.04	< 1.00	4.79	1.07	26.80	153.00
		15.80	184.00	0.15	[19.00]	< 0.40	< 0.60	5.14	7.28	11.80	< 0.04	< 1.00	5.83	0.90	30.20	201.00
	2															
	3															
	mean	12.58	130.00	0.16	7.95	< 0.40	< 0.60	4.53	4.96	19.92	< 0.04	< 1.00	6.30	0.83	27.78	152.00

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 West	12.80	520.00	0.27	20.30	< 0.40	< 0.60	3.42	5.48	12.50	< 0.04	< 1.00	[22.00]	0.92	36.10	534.00
		14.20	302.00	0.12	28.20	< 0.40	< 0.60	2.75	5.50	7.25	< 0.04	< 1.00	4.19	0.88	35.70	311.00
	1 East	15.20	329.00	0.20	3.42	< 0.40	< 0.60	0.80	5.73	6.00	< 0.04	< 1.00	2.55	0.86	33.90	319.00
		13.20	153.00	0.12	5.72	< 0.40	< 0.60	1.99	5.22	6.58	< 0.04	< 1.00	1.85	0.78	29.20	168.00
	2															
	3															
	mean	13.88	326.00	0.18	14.41	< 0.40	< 0.60	2.24	5.48	8.08	< 0.04	< 1.00	7.65	0.81	33.73	333.00

[ ] Indicates an outlier

TABLE 18
July 1988 Vegetation Samples – t tests

Vegetation samples
July 1988

Two sample "t" test

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	1.88	1.48	1.32	0.15			2.67	0.85	2.93			1.31	1.13	4.58	1.47
	1 East	2.73	1.40	2.01	0.06			0.14	1.50	1.35			0.85	3.81	0.28	1.48
	2															
T	3															
Sludge vs. Control	1 West	2.51	0.87	0.97	4.85			0.53	0.09	1.48			1.12	0.33	2.12	0.87
	1 East	4.00	1.36	1.34	0.81			3.28	6.09	1.76			1.31	9.69	1.31	1.36
	2															
T	3															
Sludge vs. Fertilized	1 West	3.17	2.63	0.86	5.15			2.72	4.00	2.32			0.62	0.86	5.32	2.65
	1 East	0.08	0.90	0.53	1.12			3.09	0.28	2.59			4.98	1.76	1.05	0.84
	2															
T	3															

At the 90% level of confidence, t = 2.920

$t = |\bar{X}_1 - \bar{X}_2| / (Sc * (.5 + .5)^2)$

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad H_a : \bar{X}_1 <> \bar{X}_2$

Calculation of Sc

Vegetation samples
July 1988

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	0.56	519.00	0.22	1.54	0.00	0.00	0.66	0.83	8.05	0.00	0.00	3.26	0.07	3.21	511.00
	1 East	1.50	28.46	0.04	11.00	0.00	0.00	0.99	1.42	10.21	0.00	0.00	6.67	0.09	2.30	24.33
	2															
	3															
Sludge vs. Control	1 West	0.66	530.32	0.23	4.20	0.00	0.00	0.57	0.75	2.63	0.00	0.00	9.02	0.12	2.76	523.02
	1 East	1.00	88.14	0.04	8.75	0.00	0.00	0.87	0.28	10.10	0.00	0.00	6.66	0.05	2.82	75.61
	2															
	3															
Sludge vs. Fertilized	1 West	0.65	109.02	0.08	4.00	0.00	0.00	0.59	0.36	8.47	0.00	0.00	9.37	0.14	1.66	111.50
	1 East	1.80	91.76	0.06	6.86	0.00	0.00	0.97	1.43	1.54	0.00	0.00	0.63	0.09	2.80	79.22
	2															
	3															

$Sc = ((\text{sum}((X_1 - \bar{X}_1)^2) + \text{sum}((X_2 - \bar{X}_2)^2)) / (2 + 2 - 2))^{0.5}$

TABLE 19
July 1989 Vegetation Samples – Protein Content & Trace Element Concentrations

Vegetation samples
July 1989

Concentration
(ug/g unless specified)

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 West	13.70		0.05	28.00	< 0.40	< 0.80	1.90	10.60	< 6.00	< 0.04	< 1.00	1.00	0.30	22.50	
		14.30		0.10	17.20	< 0.40	< 0.80	1.50	11.40	< 6.00	0.06	< 1.00	1.00	0.50	20.70	
	1 East	12.70		0.05	10.90	< 0.40	< 0.80	1.40	9.10	< 6.00	< 0.04	< 1.00	1.80	0.50	21.20	
		14.90		0.14	7.00	< 0.40	< 0.80	1.50	8.10	< 6.00	< 0.04	< 1.00	3.40	0.50	19.40	
	2	11.20		0.05	10.90	< 0.40	< 0.80	1.30	7.00	< 6.00	< 0.04	< 1.00	2.10	0.50	17.20	
		12.60		0.05	8.20	< 0.40	< 0.80	1.20	9.00	< 6.00	< 0.04	< 1.00	1.00	1.40	19.70	
		11.70		0.05	11.30	< 0.40	< 0.80	1.00	10.70	< 6.00	< 0.04	< 1.00	1.50	1.00	18.50	
	3															
	mean	13.01		0.07	13.36	< 0.40	< 0.80	1.40	9.41	< 6.00	< 0.04	< 1.00	1.69	0.67	19.89	

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 West	13.80		0.05	23.10	< 0.40	< 0.80	1.60	8.70	< 6.00	< 0.04	< 1.00	1.00	0.40	17.90	
		12.20		0.05	13.80	< 0.40	< 0.80	1.40	8.10	< 6.00	< 0.04	< 1.00	2.90	0.60	21.40	
	1 East	13.80		0.26	27.00	< 0.40	< 0.80	2.00	9.80	< 6.00	< 0.04	< 1.00	6.70	0.60	23.50	
		16.80		0.14	13.30	< 0.40	< 0.80	1.10	7.00	< 6.00	< 0.04	1.40	5.20	0.80	20.40	
		15.50		0.10	8.00	< 0.40	< 0.80	1.40	7.70	< 6.00	< 0.04	< 1.00	4.20	0.70	20.00	
		12.90		0.05	7.90	< 0.40	< 0.80	1.40	7.80	< 6.00	< 0.04	< 1.00	2.80	0.60	17.90	
	2															
	3	23.30		0.25	10.60	< 0.40	< 0.80	1.90	10.60	< 6.00	< 0.04	< 1.00	2.40	0.30	22.60	
		24.10		0.26	14.20	< 0.40	< 0.80	1.70	14.10	< 6.00	< 0.04	< 1.00	1.00	0.90	23.90	
	mean	16.55		0.15	14.71	< 0.40	< 0.80	1.56	9.23	< 6.00	< 0.04	1.05	3.28	0.59	20.96	

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 West	14.80		0.16	22.40	< 0.40	< 0.80	1.30	9.80	< 6.00	< 0.04	< 1.00	3.30	0.50	27.00	
		16.40		0.05	7.80	< 0.40	< 0.80	1.80	10.70	< 6.00	< 0.04	< 1.00	1.10	0.40	38.00	
	1 East	16.20		0.08	10.40	< 0.40	< 0.80	2.00	8.10	< 6.00	< 0.04	< 1.00	1.00	0.50	23.00	
		20.40		0.05	48.00	< 0.40	< 0.80	2.30	8.40	< 6.00	< 0.04	< 1.00	3.40	0.20	24.10	
		16.00		0.13	20.30	< 0.40	< 0.80	1.80	9.80	< 6.00	< 0.04	< 1.00	4.20	0.20	26.10	
		19.90		0.09	11.00	< 0.40	< 0.80	1.70	9.20	< 6.00	< 0.04	< 1.00	4.70	0.30	24.60	
		16.60		0.05	22.60	< 0.40	< 0.80	0.80	9.10	< 6.00	< 0.04	< 1.00	5.50	0.30	26.60	
		16.70		0.08	14.70	< 0.40	< 0.80	1.00	10.80	< 6.00	< 0.04	< 1.00	4.90	0.20	26.50	
	2	15.00		0.05	29.10	< 0.40	< 0.80	1.00	10.40	< 6.00	< 0.04	< 1.00	1.00	0.40	24.10	
		14.70		0.05	9.10	< 0.40	< 0.80	1.40	9.30	< 6.00	< 0.04	< 1.00	1.00	0.20	22.30	
		15.40		0.05	12.20	< 0.40	< 0.80	1.20	9.70	< 6.00	< 0.04	< 1.00	1.00	0.40	23.70	
		15.00		0.05	7.10	< 0.40	< 0.80	1.40	8.20	< 6.00	< 0.04	1.50	1.00	0.20	20.70	
	3	23.40		0.11	15.70	< 0.40	< 0.80	1.00	11.40	< 6.00	< 0.04	< 1.00	1.10	0.20	24.90	
		24.90		0.22	57.30	< 0.40	< 0.80	2.00	13.40	< 6.00	< 0.04	< 1.00	3.40	0.30	25.60	
	mean	17.81		0.09	20.81	< 0.40	< 0.80	1.48	9.73	< 6.00	< 0.04	1.04	2.61	0.31	25.51	

TABLE 20
July 1989 Vegetation Samples – t Tests

Vegetation samples
July 1989

Two sample 'T' test

At the 90% level of Confidence

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	T
Fertilized vs. Control	1 West	1.17		1.00	0.59			0.89	5.20		1.00		1.00	0.71	0.99	2.920
	1 East	0.65		0.60	0.74			0.09	0.55			0.67	1.60	3.33	0.08	2.132
	2															
T	3															
Sludge vs. Control	1 West	1.80		0.31	1.28			0.00	1.43		1.34		0.83	0.77	1.33	2.353
	1 East	3.13		0.44	1.30			0.19	0.35				2.67	6.34	5.36	2.105
	2	8.34			0.71			0.62	0.48			0.85	2.00	2.92	3.87	2.105
T	3															
Sludge vs. Fertilized	1 West	2.35		0.88	0.71			0.72	1.12				0.12	0.39	1.63	2.353
	1 East	3.03		1.34	1.11			0.18	0.98			1.14	0.22	10.67	4.38	1.895
	2															
T	3	0.53		1.75	1.15			0.59	0.02				0.41	1.15	2.91	2.920

$$t = |\bar{X}_1 - \bar{X}_2| / (Sc * (1/n_1 + 1/n_2)^{\wedge}2)$$

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad$ $H_a : \bar{X}_1 <> \bar{X}_2$

Calculation of Sc

Vegetation samples
July 1989

	SITE	Protein (%)	Al	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized vs. Control	1 West	0.85		0.03	7.19	0.00	0.00	0.22	0.50	0.00	0.01	0.00	0.95	0.14	1.97	
	1 East	1.70		0.09	7.91	0.00	0.00	0.33	1.10	0.00	0.00	0.17	1.53	0.04	2.10	
	2															
	3															
Sludge vs. Control	1 West	1.50		0.05	7.79	0.00	0.00	0.34	1.13	0.00	0.01	0.00	1.06	0.09	6.36	
	1 East	1.73		0.04	13.44	0.00	0.00	0.56	1.50	0.00	0.00	0.00	0.87	0.05	1.18	
	2	0.50		0.00	7.85	0.00	0.00	0.18	1.37	0.00	0.00	0.19	0.35	0.30	1.43	
	3															
Sludge vs. Fertilized	1 West	1.82		0.05	7.50	0.00	0.00	0.31	1.11	0.00	0.00	0.00	1.31	0.09	6.50	
	1 East	1.76		0.07	12.75	0.00	0.00	0.53	1.47	0.00	0.00	0.13	1.23	0.05	1.75	
	2															
	3	0.85		0.06	20.88	0.00	0.00	0.51	2.02	0.00	0.00	0.00	1.35	0.30	0.65	

$$Sc = ((\text{sum}((X_1 - \bar{X}_1)^{\wedge}2) + \text{sum}((X_2 - \bar{X}_2)^{\wedge}2)) / (n_1 + n_2 - 2))^{\wedge}0.5$$

APPENDIX D
SOIL DATA

Note: All calculations done on Lotus, therefore there may be slight differences from manual calculations.

TABLE 21
September 1987 Soil Samples – Background Nutrient Content & Trace Element Concentrations

Soil samples Sept 1987

Concentration (µg/g unless specified)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 (0-15cm)		0.12					11.10		< 2.00	14.40	106.70	32.20	12.90	0.02		34.60	0.61	112.10	
			0.10					10.90		< 2.00	13.80	101.70	32.50	13.20	0.02		31.50	0.58	115.10	
	1 (15-30cm)	7.84		6.00	4.00	12.00														
		7.76		6.00	2.40	13.00														
	1 (30-60cm)	8.12		6.00	3.10	25.00														
		7.90		6.00	3.00	48.00														
	(SAMPLING DEPTH)																			

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 (0-15cm)		0.14					11.00		< 2.00	13.30	101.50	31.50	12.90	0.02		31.00	0.53	111.80	
			0.22					11.00		< 2.00	14.00	97.00	32.50	13.00	0.00		29.40	0.66	116.60	
	1 (15-30cm)	7.54		0.50	6.20	13.00														
	1 (30-60cm)	7.87		0.50	4.50	21.00														
	(SAMPLING DEPTH)																			

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 (0-15cm)		0.15					10.60		< 2.00	11.40	89.80	31.70	15.70	0.01		34.90	0.66	110.50	
			0.17					10.40		< 2.00	12.50	100.10	32.60	16.30	0.01		36.20	0.67	115.60	
	1 (15-30cm)	7.66		5.00	2.60	11.00														
		8.08		5.00	4.60	12.00														
	1 (30-60cm)	8.00		5.00	2.50	14.00														
		7.80		5.00	7.10	66.00														
	(SAMPLING DEPTH)																			

	SITE		pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Data (Background)	1 (0-15cm)	Mean		0.16					10.76		< 2.00	13.23	100.98	32.02	14.80	0.01		32.83	0.62	113.02	
		Median		0.17					11.00		< 2.00	13.90	101.50	32.50	13.20	0.02		34.50	0.66	115.10	
		Maximum		0.22					11.10		< 2.00	14.40	106.70	32.60	16.30	0.02		36.20	0.66	116.60	
	1 (15-30cm)	Mean	7.90		4.10	4.60	12.20														
		Median	7.66		5.00	4.00	12.00														
		Maximum	8.08		5.00	6.20	13.00														
	1 (30-60cm)	Mean	7.97		4.10	4.06	34.80														
		Median	7.90		5.00	3.10	25.00														
		Maximum	8.12		5.00	7.10	66.00														

TABLE 22
September 1988 Soil Samples – Nutrient Content

Soil samples Sept 1988

Concentration (kg/g unless specified)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 (0-15cm)		0.18	2.22	2.58		2.22													
			0.22	6.00	3.91		4.04													
	1 (15-30cm)		0.12	6.10	0.20															
			0.16	10.48	0.00															
	1 (30-60cm)		0.09	4.19	0.12															
			0.11	4.83	0.01															
	2 (0-15cm)		0.20	12.53	5.72		3.82													
	2 (15-30cm)		0.13	9.11	2.62															
	2 (30-60cm)		0.11	5.78	0.42															

(SAMPLING DEPTH)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 (0-15cm)		0.23	4.36	2.34		4.30													
			0.18	3.66	3.30		2.74													
	1 (15-30cm)		0.14	4.03	0.76															
			0.14	4.01	2.16															
	1 (30-60cm)		0.10	0.23	0.01															
			0.10	0.02	0.01															
	3 (0-15cm)		0.20	4.12	9.22		6.30													
	3 (15-30cm)		0.16	3.64	6.15															
	3 (30-60cm)		0.13	0.58	1.68															

(SAMPLING DEPTH)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 (0-15cm)		0.22	2.17	14.70		4.82													
			0.19	1.21	9.15		4.30													
	1 (15-30cm)		0.16	5.58	2.35															
			0.14	4.61	1.30															
	1 (30-60cm)		0.11	4.61	0.26															
			0.10	5.70	0.05															
	2 (0-15cm)		0.22	2.48	22.70		6.54													
	2 (15-30cm)		0.16	6.81	0.46															
	2 (30-60cm)		0.10	4.58	0.60															
	3 (0-15cm)		0.19	6.79	8.75		4.96													
	3 (15-30cm)		0.14	5.66	4.50															
	3 (30-60cm)		0.10	6.91	1.16															

(SAMPLING DEPTH)

Moore 1988	SITE 1	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	(0-15cm)		0.20	4.11	3.27		3.13													
	(15-30cm)		0.14	5.29	0.40															
	(30-60cm)		0.10	4.37	0.07															
Fertilized	(0-15cm)		0.21	4.02	2.62		3.52													
	(15-30cm)		0.14	4.02	1.47															
	(30-60cm)		0.10	6.13	0.01															
Sludged	(0-15cm)		0.21	1.89	11.83		4.58													
	(15-30cm)		0.15	5.10	1.63															
	(30-60cm)		0.11	5.16	0.17															

(SAMPLING DEPTH)

TABLE 23
September 1988 Soil Samples – t tests

Soil Samples
September 1988

Two Sample 't' test

At the
95% Level
of Confidence

SITE 1		pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	't'
Control	(0-15cm)		1.86																	2.447
vs Background	(15-30cm)			2.20	3.16															2.571
	(30-60cm)			0.18	2.76															2.571
Fertilized	(0-15cm)		1.30																	2.447
vs Background	(15-30cm)			0.05	2.13															2.571
	(30-60cm)			1.34	3.57															2.571
Sludged	(0-15cm)		1.46																	2.447
vs Background	(15-30cm)			0.05	1.56															2.571
	(30-60cm)			0.09	2.69															2.571

$$t = |\bar{X}_1 - \bar{X}_2| / (Sc * (1/n_1 + 1/n_2)^{\wedge}.5)$$

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad$ $H_a : \bar{X}_1 <> \bar{X}_2$

Soil Samples
September 1988

Calculation of Sc

SITE 1		pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	(0-15cm)		0.6372																	
vs Background	(15-30cm)			0.2712	1.3624															
	(30-60cm)			1.6078	1.7265															
Fertilized	(0-15cm)		0.0982																	
vs Background	(15-30cm)			1.5000	1.4240															
	(30-60cm)			1.6012	1.3585															
Sludged	(0-15cm)		0.5364																	
vs Background	(15-30cm)			1.5259	1.3965															
	(30-60cm)			1.6327	1.7287															

$$Sc = ((\text{sum}((X_1 - \bar{X}_1)^{\wedge}2) + \text{sum}((X_2 - \bar{X}_2)^{\wedge}2)) / (n_1 + n_2 - 2))^{\wedge}0.5$$

TABLE 24
September 1989 Soil Samples – Nutrient Content & Trace Element Concentrations

Soil samples Sept 1989

Concentration (µg/g unless specified)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control	1 (0-15cm)		0.23	11.00	1.00	12.00	18.50	4.30	4330.00	0.54	10.00	62.00	24.00	10.00	< 0.04	< 0.50	36.20	0.60	97.00	
			0.19	7.40	0.88	13.00	0.30	10.40	2970.00	0.33	12.00	66.20	26.50	12.00	< 0.04	< 0.50	37.30	0.60	112.00	
	1 (15-30cm)	8.00	0.15	4.00	0.40	12.50														
		7.90	0.16	2.00	0.34	16.00														
	1 (30-60cm)	8.20	0.11	4.90	1.60	15.00														
		8.00	0.14	2.10	0.43	14.00														
	2 (0-15cm)		0.19	6.70	0.30	12.00	0.00	6.20	3780.00	0.50	10.00	62.00	25.00	10.00	< 0.04	< 0.50	34.40	0.50	96.40	
	2 (15-30cm)	8.00	0.14	2.50	0.30	16.00														
	2 (30-60cm)	8.20	0.09	13.50	0.30	16.00														

(SAMPLING DEPTH)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Fertilized	1 (0-15cm)		0.23	6.70	2.40	11.00	23.50	10.40	2970.00	0.33	12.00	66.20	26.50	12.00	< 0.04	< 0.50	37.30	0.60	112.00	
			0.19	6.40	0.68	12.00	18.60	3.90	4100.00	0.25	10.00	62.60	25.40	13.00	< 0.04	< 0.50	34.50	0.43	100.00	
	1 (15-30cm)	7.90	0.14	2.00	0.30	11.00														
		7.90	0.15	2.00	1.60	12.00														
	1 (30-60cm)	8.20	0.10	5.50	0.30	10.00														
		8.00	0.13	4.70	0.72	12.00														
	2 (0-15cm)		0.20	6.10	0.90	26.00	23.20	7.50	3960.00	0.44	12.00	74.40	29.30	10.00	< 0.04	< 0.50	41.20	0.52	106.00	
			0.21	6.40	2.40	36.00	30.40	3.70	4740.00	0.38	13.00	74.10	30.00	30.00	< 0.04	< 0.50	42.40	0.67	110.00	
	2 (15-30cm)	7.90	0.10	2.00	1.60	28.00														
		7.80	0.16	0.20	2.60	30.00														
	2 (30-60cm)	7.70	0.14	2.00	0.30	1400.00														
		7.80	0.13	4.80	0.47	71.00														

(SAMPLING DEPTH)

	SITE	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Sludge	1 (0-15cm)		0.26	7.60	3.20	36.00	31.70	8.60	2620.00	0.45	11.00	63.40	33.70	15.00	0.05	< 0.50	34.60	0.60	112.00	
			0.20	6.20	1.20	29.00	20.80	11.10	2520.00	0.45	10.00	62.70	32.60	11.00	< 0.04	< 0.50	36.70	0.60	111.00	
	1 (15-30cm)	7.90	0.15	2.00	1.20	32.00														
		7.80	0.15	0.60	4.30	34.00														
	1 (30-60cm)	8.10	0.10	2.20	0.30	13.00														
		8.00	0.13	4.60	1.20	12.00														
	2 (0-15cm)		0.21	6.40	1.30	30.00	24.80	4.30	4710.00	0.25	9.00	68.40	28.60	12.00	0.06	< 0.50	36.90	0.58	108.00	
	2 (15-30cm)	7.80	0.10	2.00	1.50	41.00														
	2 (30-60cm)	8.10	0.11	2.20	0.30	15.00														
	3 (0-15cm)		0.18	2.00	0.30	32.00	23.40	10.70	2870.00	0.71	14.00	72.60	34.80	14.00	< 0.04	< 0.50	41.90	0.48	111.00	
	3 (15-30cm)	7.80	0.16	2.00	0.30	28.00														
	3 (30-60cm)	7.70	0.11	2.00	0.30	300.00														

(SAMPLING DEPTH)

	SITE 1	pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Means 1989	Control																			
	(0-15cm)		0.21	9.20	0.79	12.50	12.40	7.35	3650.00	0.44	11.00	64.05	29.55	11.00	< 0.04	< 0.50	36.75	0.60	104.50	
	(15-30cm)	7.90	0.17	3.00	0.37	14.00														
	(30-60cm)	8.10	0.13	3.50	1.02	14.50														
	Fertilized																			
	(0-15cm)		0.21	7.05	1.54	11.50	21.00	7.15	3535.00	0.39	11.00	64.00	28.05	12.50	< 0.04	< 0.50	36.60	0.52	106.00	
	(15-30cm)	7.80	0.16	2.60	1.05	11.50														
	(30-60cm)	8.10	0.12	6.10	0.51	14.00														
	Sludged																			
	(0-15cm)		0.23	7.65	2.20	32.50	29.30	9.65	2670.00	0.45	10.50	63.05	33.25	13.00	0.05	< 0.50	36.60	0.55	111.50	
	(15-30cm)	7.80	0.17	4.45	2.75	36.00														
	(30-60cm)	8.05	0.12	3.50	0.75	12.50														

TABLE 25
September 1989 Soil Samples – t tests

Soil Samples
September 1989

Two Sample 't' test

SITE 1		pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	At the 95% Level of Confidence 't'
Control vs Background	(0-15cm)		1.07					2.36		31.62	2.34	18.60	9.66	2.36			1.00	0.48	2.26	2.447
	(15-30cm)	0.06		0.69	3.20	1.48														2.571
	(30-60cm)	1.25		0.36	2.06	1.26														2.571
Fertilized vs Background	(0-15cm)		1.59					2.35		90.69	2.34	19.78	9.37	1.26			1.42	1.79	2.26	2.447
	(15-30cm)	1.06		0.83	2.45	1.03														2.571
	(30-60cm)	1.25		0.66	2.45	1.26														2.571
Sludged vs Background	(0-15cm)		2.03					1.49			3.17	17.76	2.34	0.67			1.85	1.43	1.14	2.447
	(15-30cm)	1.06		0.16	0.69	13.36														2.571
	(30-60cm)	0.85		0.36	2.26	1.36														2.571

$$t = \frac{|\bar{X}_1 - \bar{X}_2|}{(Se \cdot (1/n_1 + 1/n_2)^{.5})}$$

$H_0 : \bar{X}_1 = \bar{X}_2$ $\quad H_A : \bar{X}_1 <> \bar{X}_2$

Calculation of Se

SITE 1		pH	TKN (% wt)	NH3-N	NO3-N	EXT.S	EXT.P	As	B	Cd	Co	Cr	Cu	Pb	Hg	Mo	Ni	Se	Zn	Fe
Control vs Background	(0-15cm)		0.0884					1.7901		0.0000	1.1071	2.6924	1.2216	1.5406			2.4882	0.0540	4.7583	
	(15-30cm)	0.1187		1.9079	1.3566	1.4887														
	(30-60cm)	0.1255		2.0060	1.7673	19.3251														
Fertilized vs Background	(0-15cm)		0.0372					1.6844		0.0231	1.1071	2.6996	1.0127	1.4572			2.5062	0.0730	4.1801	
	(15-30cm)	0.1017		1.6866	1.4370	0.8124														
	(30-60cm)	0.1202		1.8177	1.7332	19.3439														
Sludged vs Background	(0-15cm)		0.0082					0.7074		0.0000	1.0648	2.6170	0.9400	1.8367			2.7207	0.0612	2.2075	
	(15-30cm)	0.1017		2.2751	1.6736	2.0369														
	(30-60cm)	0.1071		1.9788	1.7514	19.3251														

$$Se = \frac{((\text{sum}_1 (X_1 - \bar{X}_1)^2) + \text{sum}_2 ((X_2 - \bar{X}_2)^2))}{(n_1 + n_2 - 2))^{.5}}$$

APPENDIX E
CHARACTERISTICS OF REGINA MUNICIPAL SLUDGE

TABLE 26
CHARACTERISTICS OF APPLIED SLUDGE

Parameter (ug/g unless specified)	Range from City of Regina data	October 1987[e]		May 1988[f]		September 1988[e]	Median of all data	
TKN (%)	0.1 - 3.8	1.52	(1.43)[a]	1.94	(1.98)	1.22	1.95	[28]
NO_3-N	< 0.5 - 5.7	---[b]		4.56	(5.66)	6.02	3.93	[10]
NH_4-N	74 - 710	---		2590	(672)	366.4	585	[10]
TC (%)	---	---		---		26.7	26.7	[1]
TP (%)	0.78 - 2.10	---		1.26	(1.25)	0.91	0.95	[26]
pH (pH units)	7.64	---		6.89	(6.89)	7.33	7.11	[4]
Cond. (umho/cm)	4400	---		3640	(530)	4050	3845	[4]
TS (%)	30.2 - 43.9	---		---		---	35.0	[23]
VSS (%)	14.9	---		---		---	14.9	[1]
Ext.-P	1200	---		1.25	(142)	106	124	[4]
SAR[d](abs. units)	---	---		---		3.5	3.5	[1]
Al (%)	2.70	2.80	(2.75)	2.82	(2.97)	1.78	2.77	[6]
As	1.6 - 15.0	6.6	(6.4)	5.13	(4.95)	6.84	6.5	[27]
B	< 10 - 480	---		2160	(2230)	2720	18	[26]
Ca (%)	8.3	---		4.17	(4.22)	6.60	5.41	[4]
Cd	2.8 - 8.8	4.1	(4.6)	5.2	(5.2)	3.5	4.8	[28]
Cl	2220	---		1042	(1245)	852	1143	[4]
Co	10	9.1	(8.5)	13.1	(12.3)	11.3	10.6	[6]
Cr	80 - 360	228.5	(225.3)	158	(145)	273	100	[28]
Cu	720 - 1400	780.0	(788.5)	1000	(953)	778	865	[28]
Fe (%)	1.30 - 2.80	---		1.92	(1.96)	1.30	1.94	[26]
Hg	0.9 - 16.0	1.91	(2.00)	5.34	(5.04)	2.38	3.50	[28]
K (%)	0.19 - 0.54	---		0.74	(0.74)	0.62	0.36	[26]
Mg (%)	0.8 - 1.9	---		1.02	(1.06)	1.30	1.3	[26]
Mn	400 - 13000	---		880	(829)	1620	824	[26]
Mo	< 4	---		8.46	(7.82)	7.04	7.43	[4]
Na	750 - 1500	---		5650	(6270)	7740	1100	[21]
Ni	23 - 42	34.0	(32.4)	37.0	(33.5)	29.1	32.2	[28]
Pb	175 - 380	235.7	(234.7)	170	(166)	146	300	[28]
Se	< 0.5	3.33	(1.07)	3.03	(2.92)	3.10	2.97	[6]
SO_4	6440	---		601	(1220)	500	910	[4]
Zn	560 - 2100	694.6	(702.1)	768	(749)	532	715	[28]

.Source: Goalen et. al., 1989

Indicates an outlying value.

a split sample

b not analyzed

c number of samples used to calculate median

d sodium adsorption ratio

e Site 1 sludge plot

f Site 2 sludge plot

APPENDIX F
CHARACTERISTICS OF COMMERCIAL FERTILIZERS

TABLE 27
Characteristics of Commercial Fertilizers

TYPICAL ANALYSIS DATA

(Guaranteed analysis may be lower than data shown below)

CHEMICAL ANALYSIS	11-51-0	16-20-0	34-0-0	23-24-0	26-13-0	18-35-0	17-17-17	8-25-25	13-16-10	10-34-10	46-0-0	27-27-0	34-17-0	19-39-0	18-46-0	0-0-62
Total N %	11.1	16.1	34.4	23.4	26.3	18.3	17.1	8.6	13.1	10.5	46.2	27.5	34.3	19.2	18.1	0.0
Ammoniacal N %	11.1	16.1	17.2	14.5	16.0	13.2	13.0	7.1	13.1	10.5	0.0	5.9	3.7	8.5	18.1	0.0
Nitrate N %	0.0	0.0	17.2	9.0	10.3	5.1	4.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Urea N %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.2	21.6	30.6	10.7	0	0.0
Ammonium Nitrate %	0.0	0.0	98.5	52.5	60.0	31.0	39.0	9.0	0.0	0.0	0.0	0.0	0.0	0	0	0.0
Urea %	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	46.7	66.3	23.2	0	0.0
Water Soluble N %	11.1	16.1	34.4	23.2	26.2	18.2	17.0	8.5	13.00	10.5	46.2	27.5	34.4	19.2	18.1	0.0
Total P_2O_5 %	51.2	20.2	0.0	24.2	13.2	35.3	17.1	25.6	16.1	34.2	0.0	27.2	17.2	39.2	46.2	0.0
Available P_2O_5 %	51.1	20.1	0.0	24.1	13.2	35.2	17.1	25.5	16.1	34.1	0.0	27.1	17.2	39.2	46.1	0.0
Water Soluble P_2O_5 %	46.0	19.5	0.0	22.9	12.1	34.0	16.4	24.0	15.5	33.1	0.0	24.2	15.8	36.2	39.2	0.0
Soluble K_2O %	0.0	0.0	0.0	0.0	0.0	0.0	17.0	25.4	10.1	10.2	0.0	0.0	0.0	0.0	0	62.3
Moisture %	0.8	0.4	0.1	0.3	0.3	0.5	0.5	0.3	0.3	0.3	0.2	0.5	0.5	0.6	0.8	0.15
Free Acid (H_3PO_4) %	0.1	0.1	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0	0.0
pH	4.1	3.9	5.5	4.6	4.1	4.5	6.3	4.0	3.9	3.7	7.3	4.0	4.2	4.0	6.6	6.7
Coating Agent %	0.0	0.0	1.2	0.6	0.7	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Calcium (CaO) %	2.0	2.0	1.0	1.0	0.7	1.5	0.7	0.9	1.7	1.0	0.0	1.0	0.6	1.4	1.8	0.02
Sulphur (S) %	1.8	15.3	0.0	1.1	3.0	1.5	0.8	1.0	12.2	5.2	0.0	1.1	0.7	1.5	1.7	0.006
Iron (Fe_2O_3) %	0.7	0.3	0.0	0.3	0.1	0.5	0.2	0.3	0.2	0.4	0.0	0.4	0.3	0.6	0.6	0.0
Aluminum (Al_2O_3) %	1.5	0.6	0.0	0.7	0.3	1.1	0.5	0.8	0.5	0.9	0.0	0.7	0.4	1.0	1.3	0.0
Sodium (Na) %	0.3	0.2	0.0	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.0	0.2	0.1	0.3	0.3	0.0
Chloride (Cl) %	0.0	0.0	0.0	0.0	0.0	0.0	12.1	18.2	7.6	0.0	0.0	0.0	0.0	0.0	0.0	47.47
Magnesium (MgO) %	1.5	0.6	0.0	0.8	0.4	1.3	0.6	0.8	0.5	1.0	0.0	0.4	0.2	0.5	0.6	0.02
Manganese (Mn) PPM	100	100	0.0	50	30	75	35	50	60	60	0.0	55	35	75	100	-
Copper (Cu) PPM	35	15	0.0	15	10	25	10	20	10	20	0.0	15	10	25	30	-
Zinc (Zn) PPM	130	65	0.0	65	20	100	50	70	55	90	0.0	65	20	100	115	-
Molybdenum (Mo) PPM	13	8	0.0	8	5	10	5	8	5	10	0.0	8	5	10	12	-

PHYSICAL CHARACTERISTICS

Type	HOMO	HOMO	HOMO	HETERO	HETERO	HETERO	HETERO	HETERO	HETERO	HETERO	HOMO	HETERO	HETERO	HETERO	HOMO	HOMO
Critical RH @ 23°C*	92	92	85	85	85	85	85	80	86	80	78	85	85	85	83	84
Bulk Density KG/M³ (LBS/FT.³)	993(62)	961(60)	913(57)	[illegible](56)	935(58)	961(60)	993(62)	1025(64)	993(62)	993(62)	769(48)	881(55)	849(53)	929(58)	929(58)	1073(67)
Angle of REPOSE	30°	29°	25°	26°	28°	29°	31°	31°	30°	31°	31°	33°	32°	33°	34°	35°

*At 23°C the fertilizers listed begin to absorb moisture at or above the relative humidities shown, mixing fertilizers together can often cause absorption at a very low R.H.
For Example: Urea and Ammonium Nitrate will absorb moisture when the R.H. is only 18.1% (see table Page S3-2)

MAKE UP OF HETEROGENEOUS BLENDS

Kg/TONNE (POUNDS/TON)

PRODUCT	18-35-0	19-39-0	23-24-0	27-27-0	26-13-0	34-17-0	8-25-25	10-34-10	13-16-10	17-17-17
34-0-0 Ammonium Nitrate	310(620)	-	625(1050)	-	600(1200)	-	90(180)	-	-	390(780)
46-0-0 Urea	-	232(464)	-	467(934)	-	683(1326)	-	-	-	-
11-51-0 Ammonium Phosphate	690(1380)	768(1536)	475(950)	533(1066)	165(330)	337(674)	500(1000)	565(1130)	-	335(670)
16-20-0 Ammonium Phosphate Sulphate	-	-	-	-	235(470)	-	-	270(540)	830(1660)	-
0-0-62 Potash	-	-	-	-	-	-	410(820)	165(330)	170(340)	275(550)

Source: Saskatchewan Agriculture, 1987

APPENDIX G
NUTRIENT ACCUMULATION CALCULATIONS

Note: All calculations done on Lotus,
therefore there may be slight
differences from manual
calculations

TABLE 28
Crop Available Nitrogen Calculated Using The USEPA Method, For Specific Rates of Sludge Application

Year	S (tonne/ha)	kv	NO3 %	NH4 %	f()	Tkn %	Available Mineralized No %	No %	Np (kg/ha)	Np (lb/acre)
1	25	1	0.0004	0.0585	0.2	1.95	1.95	0.39	11.22	12.56
2					0.1		1.56	0.16	3.90	4.37
3					0.05		1.40	0.07	1.75	1.96
4					0.03		1.33	0.04	1.00	1.12
5					0.03		1.29	0.04	0.97	1.09
6					0.03		1.25	0.04	0.94	1.05
7					0.03		1.22	0.04	0.91	1.02
8					0.03		1.18	0.04	0.89	0.99
9					0.03		1.15	0.03	0.86	0.96
10					0.03		1.11	0.03	0.83	0.93

Note: The sludge characteristics used are median values taken from Appendix E

Year	S (tonne/ha)	kv	NO3 %	NH4 %	f()	Tkn %	Available Mineralized No %	No %	Np (kg/ha)	Np (lb/acre)
1	33	1	0.0004	0.0585	0.2	1.95	1.95	0.39	14.81	16.58
2					0.1		1.56	0.16	5.15	5.76
3					0.05		1.40	0.07	2.32	2.59
4					0.03		1.33	0.04	1.32	1.48
5					0.03		1.29	0.04	1.28	1.43
6					0.03		1.25	0.04	1.24	1.39
7					0.03		1.22	0.04	1.20	1.35
8					0.03		1.18	0.04	1.17	1.31
9					0.03		1.15	0.03	1.13	1.27
10					0.03		1.11	0.03	1.10	1.23

Note: The sludge characteristics used are median values taken from Appendix E

Year	S (tonne/ha)	kv	NO3 %	NH4 %	f()	Tkn %	Available Mineralized No %	No %	Np (kg/ha)	Np (lb/acre)
1	45	1	0.0004	0.0585	0.2	1.95	1.95	0.39	20.19	22.61
2					0.1		1.56	0.16	7.02	7.86
3					0.05		1.40	0.07	3.16	3.54
4					0.03		1.33	0.04	1.80	2.02
5					0.03		1.29	0.04	1.75	1.96
6					0.03		1.25	0.04	1.69	1.90
7					0.03		1.22	0.04	1.64	1.84
8					0.03		1.18	0.04	1.59	1.78
9					0.03		1.15	0.03	1.55	1.73
10					0.03		1.11	0.03	1.50	1.68

Note: The sludge characteristics used are median values taken from Appendix E

TABLE 29
Reccomended Rates of application for Wheat Crops Grown In The Dark Brown Soil Zone of Saskatchewan (Nuttal et.al., page 6)

Nitrogen N, Kg/ha (lb/ac)

Stubble fields		Summerfallow	
25-65	(25-60)	0-15	(0-15)

TABLE 30
Crop Available Nitrogen Resuting From Sludge Application

Site 1 east (Stubble)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
application 1	11.22	3.90	1.75	1.00	0.97	0.94	0.91	0.89	0.86	0.83
application 2		14.81	5.15	2.32	1.32	1.28	1.24	1.20	1.17	1.13
Available N	11.22	27.92	34.82	38.14	40.43	42.65	44.81	46.90	48.92	50.89
Crop use (Kg/ha)	2.01	?	?	?	?	?	?	?	?	?
Remaining avilable N	9.21	27.92	34.82	38.14	40.43	42.65	44.81	46.90	48.92	50.89

Site 1 west (Stubble)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
application 1	11.22	3.90	1.75	1.00	0.97	0.94	0.91	0.89	0.86	0.83
no second application										
Available N	11.22	4.43	-21.13	-20.13	-19.16	-18.22	-17.31	-16.42	-15.56	-14.73
Crop use (Kg/ha)	10.69	27.31	?	?	?	?	?	?	?	?
Remaining avilable N	0.53	-22.89	-21.13	-20.13	-19.16	-18.22	-17.31	-16.42	-15.56	-14.73

Site 2 (Summerfallow)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
application 1		20.19	7.02	3.16	1.80	1.75	1.69	1.64	1.59	1.55
no second application										
Available N		20.19	-28.60	-25.44	-23.64	-21.89	-20.20	-18.56	-16.96	-15.42
Crop use (Kg/ha)		55.81	?	?	?	?	?	?	?	?
Remaining avilable N		-35.61	-28.60	-25.44	-23.64	-21.89	-20.20	-18.56	-16.96	-15.42

Site 3 (Summerfallow)	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
application 1		11.22	3.90	1.75	1.00	0.97	0.94	0.91	0.89	0.86
no second application										
Available N		11.22	-34.21	-32.46	-31.46	-30.49	-29.55	-28.63	-27.75	-26.89
Crop use (Kg/ha)		49.33	?	?	?	?	?	?	?	?
Remaining avilable N		-38.11	-34.21	-32.46	-31.46	-30.49	-29.55	-28.63	-27.75	-26.89

Crop use of N - Calculated from Provincial Yield Averages	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Spring Wheat	32.51	56.71	75.69	90.41						
Oats	80.45	89.78								

Provincial yield averages
(Verbal Communication - Economics branch Statistics Division, Saskatchewan Agriculture)

	Spring wheat crops			Oat Crops
	bu/ac	(Kg/ha)/(Bu/ac)	Kg/ha	Kg/ha
1988	13.7	0.014883	920.4927	2606.942
1989	23.9	0.014883	1605.823	2909.294
1990	31.9	0.014883	2143.337	
1991	38.1	0.014883	2559.910	

TABLE 31
Crop Available Nitrogen Resuting From Commercial Fertilizer Application

Site 1 east (Stubble)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
application 1	30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
application 2		30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
application 3			30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available N	30.36	60.72	42.84	42.84	42.84	42.84	42.84	42.84	42.84	42.84
Crop use (Kg/ha)	n/a	17.88	n/a	?	?	?	?	?	?	?
Remaining avilable N	30.36	42.84	42.84	42.84	42.84	42.84	42.84	42.84	42.84	42.84

Rates of Application are assumed to be consistently 89.3Kg/ha (100 lb/ac) for Site 1

Site 1 west (Stubble)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
application 1	30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
application 2		30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
application 3			30.36	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Available N	30.36	60.72	46.66	27.01	27.01	27.01	27.01	27.01	27.01	27.01
Crop use (Kg/ha)	n/a	14.07	19.64	?	?	?	?	?	?	?
Remaining avilable N	30.36	46.66	27.01	27.01	27.01	27.01	27.01	27.01	27.01	27.01

Site 2 (Summerfallow)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996

No commercial fertilizer application at Site 2

Site 3 (Summerfallow)	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
application 1			4.91	0.00	0.00	0.00	0.00	0.00	0.00	0.00
no second application										
Available N		0.00	4.91	-62.21	-62.21	-62.21	-62.21	-62.21	-62.21	-62.21
Crop use (Kg/ha)		n/a	67.12	?	?	?	?	?	?	?
Remaining avilable N		0.00	-62.21	-62.21	-62.21	-62.21	-62.21	-62.21	-62.21	-62.21

Crop use of N - Calculated from Provincial Yield Averages

	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
Spring Wheat	32.51	56.71	75.69	90.41						
Oats	80.45	89.78								

Provincial yield averages
(Verbal Communication - Economics branch Statistics Division, Saskatchewan Agriculture)

	Spring wheat crops			Oat Crops
	bu/ac	(Kg/ha)/(Bu/ac)	Kg/ha	Kg/ha
1988	13.7	0.014883	920.4927	2606.942
1989	23.9	0.014883	1605.823	2909.294
1990	31.9	0.014883	2143.337	
1991	38.1	0.014883	2559.910	

APPENDIX H
LABORATORY METHODS

Set Name: Sludge and Soil Samples

Comments

Sample Preparation:

The samples were kept frozen until needed. First they were freeze dried at -50 deg C and approximately 30 millitorr and passed through a 2 millimeter sieve. A one gram portion was weighed out and digested with 15 milliliters (ml) of Nitric acid until near dryness followed by three 10 ml portions of Perchloric acid and finally with 10 ml of Hydrofluoric acid. The final solution was diluted to 100 ml in 2% Nitric acid.

Mercury Analysis:

A one gram portion (0.05 grams for 88/0014 and 88/0015) of the freeze dried sample was digested with 5 ml of Aqua Regia followed by 15 ml of 5% Potassium Permanganate solution in a hot water bath at 95 deg C. The samples were analyzed using a Manual Cold Vapor Mercury Analyzer.

Metal Anlysis:

Arsenic and Selenium analysis was performed using a Manual Hydride Generator. All other metals were analyzed by Flame Atomic Absorption Spectroscopy.

Total Kjeldahl Nitrogen Analysis;

TKN analysis was performed by Yash Kalra, Canadian Forestry Service.

Quality Control:

Two quality control samples were used during the analysis. The first was NBS BCR-141, Calcareous Loam, having a matrix similarto the soil samples. The second QC sample is EPA Municipal Digested Sludge (MDS). This sample closely matched the two sludge samples. Preparation and analysis of these QC samples was performed with the Soil and Sludge samples.

Set Name: Sludge and Soil Samples

References

Metals Digestion (excluding Mercury):

Analytical Methods Manual, August 1979, Part 4, "Total Metals in Sediments (Open Digestion)", Inland Waters Directorate Water Quality Branch, Ottawa.

Mercury Analysis:

Method 245.5, Cold Vapor Manual, Reference 1.

Metal Analysis:

Metal	Method	Reference
Aluminum	Method 202.1, FAAS, Direct Aspiration	1
Arsenic	Method 206.3, Hydride Generation	1
Cadmium	Method 213.1, FAAS, Direct Aspiration	1
Cobalt	Method 219.1, FAAS, Direst Aspiration	1
Chromium	Method 218.1, FAAS, Direct Aspiration	1
Copper	Method 220.1, FAAS, Direct Aspiration	1
Nickel	Method 249.1, FAAS, Direct Aspiration	1
Lead	Method 239.1, FAAS, Direct Aspiration	1
Selenium	Method 270.3, Hydride Generation	1
Zinc	Method 289.1, FAAS, Direct Aspiration	1

FAAS - Flame Atomic Absorption Spectroscopy

Total Kjeldahl Nitrogen:

Analysis was performed by Yash Kalra, Canadian Forestry Service, Analytical Soils Laboratory, (403) 435-7220. Analysis was carried out using a Tecator Total Kjeldahl Nitrogen Analyzer.

References:

1. U.S. Environmental Protection Agency, Methods for Chemical Analysis of Water and Wastes, Revised March 1983, EPA-600/4-79-200, Cincinnati, Ohio, U.S.A.

SDO Land Farming
References to Methodologies

Sludge and Soil Samples - 1988 & 1989

SOIL AND SLUDGE ANALYSIS:

Parameter	Method	Reference
Total Phosphorous	Total Phosphorous Determination using Total Kjeldahl Digestion	10
Extract K	Ammonium Acetate Extratable Cations, Method 4.51	9
Chlorides	Chapter 10, Soluable Salt Analysis for Soil and Waters: Chloride Determination, Method 10-94	2
Sulfates & Extract S	Extraction and Determination of Sulfur in Soils	11
Metal Digestion	Environment Canada, Soil & Sediment Digestion Procedure	12
Metals:		
Al, B, Cd, Co, Cu Cr, Mo, Ni, Zn	ICP-AES, Method 200.7	1
Na	FAAS, Method 273.1	1
Cu	FAAS, Method 220.1	1
Pb	FAAS, Method 239.1	1
As, Se	Hydride Generation	6
Hg	Cold Vapour	7

ICP-AES - Inductively Coupled Plasma-Atomic Emission Spectroscopy
FAAS - Flame Atomic Absorption Spectroscopy

SDO Land Farming
References to Methodologies

Sludge and Soil Samples - 1988 & 1989

VEGETATION ANALYSIS:

Parameter	Method	Reference
Protein-Nitrogen	Chapter 8, Nitrogen Determinations for Soils and Plant Tissue.	2
	Protein Conversion	3
Metal Digestions	Hsu, H., Plant Tissue Digestion	4
	Maynard, D.G., Unpublished Microwave Digestion Method.	5
Metals:		
Al, B, Cd, Co, Cu Cr, Mo, Ni, Pb, Fe Zn	ICP-AES, Method 200.7	1
As, Se	Hydride Generation	6
Hg	Cold Vapour	7

SOIL AND SLUDGE ANALYSIS:

Parameter	Method	Reference
pH & Conductivity	Saturated Soil Paste, Method 4.13	9.
Nitrogen Analysis:	Chapter 8, Nitrogen Determinations for Soils and Plant Tissue	2
Total Kjeldahl	Modified Kjeldahl Method, Method 3-4	
Ammonia-N	Exchangable Ammonia Determination. Method 8-33	
Nitrate-N	Nitrate Determination Calcium Hydroxide Magnesium Carbonate Extraction. Method 8-43	
Total Carbon	Soil/Sludge Total Carbon Analysis	8
Sodium Adsorption Ratio	SAR, Method 3.26	9
Extractable P	Sodium Bicarbonate Soluable P. Method 4.41	9